Calculator Programs
for
Pipe Stress Engineering

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Preface

There is probably nothing so misunderstood or so carelessly disregarded as stress analysis for piping systems in refineries, chemical processing plants, and power generating stations. Just try breaking the ice at a party sometime by saying that you are a pipe stress analyst. Yet, in all seriousness, there is probably nothing more important for the overall safety, reliability, and longevity of critical high-pressure, high-temperature piping systems than a concerned, informed, and practical analysis to make the systems comply with established codes and industry standards. A refinery that looks good is great. Saving money on the initial investment is also great. But if the owner of the plant has to shut down certain systems every six months to replace the bearings on all his rotating equipment, or the nuclear core melts to the floor like so much unsalted butter, the money saved begins to look like pocket change.

Manufacturers of the equipment used in refineries and other industrial concerns are being forced by increasing cost to use less and less material in their products to remain competitive. Pumps, compressors, turbines, and heaters are all being engineered to finer and finer degrees. This makes the induced loading on these machines from the attached piping a greater problem. Some owners of plants even require the stress analyst to add an additional 50 percent safety factor to the loads put on rotating equipment.

To counter this situation, elaborate computer programs have been written to perform highly accurate numerical analyses of structural piping systems. Such programs can analyze weight loading, thermal expansion, and response spectra earthquake vibration and can even do real-time time history dynamic analyses. But the price tag of these analyses matches their high levels of accuracy. And because most systems go through at least one revision and sometimes more, the cost of the computer-aided design can mount very quickly.

Which brings us to the reason for this text. There exist numerous empirical, statistical, or simplified methods of analysis for a great many of the stress analyst's tasks. These calculations may be used as preliminary analyses or as devises to weed out unacceptable configurations before they are subjected to a mainframe analysis, but sometimes the results can be shown to be accurate enough to be used as the final analysis in less critical systems.

However, it takes many hours, even days, to perform all the calculations entailed by many of these "simplified" methods, if done by hand, and these calculations are subject to human error. Enter the programmable calculator. Equipped with many, many data memory registers and hundreds of program steps, the programmable computer can reduce work that could take days to minutes, with none of the chances for error (except for garbage-in-garbage-out errors). With magnetic card readers to store the programs and printers to print the input data and results that such calculators provide, the stress analyst can use his/her time more productively and possibly decrease the amount of dollars spent on mainframe computer time.

I would like to stress that the programs that my reader finds herein have been subjected to the most rigorous testing to ensure the accuracy of the results and their adherence to the equations of the source documents. I personally use these programs in my daily design efforts. It is therefore in good conscience that I present them to you as complete and error-free.

Introduction to Programming

The programs in this manual are written for the Texas Instruments TI-59 and the Hewlett-Packard HP-41CV. These two machines are the two leaders in the programmable calculator market, even though the TI-59 was first introduced in 1977. Both store programs on magnetic cards, both will print data via a removable printer, both print string data as well as numeric data, and both can accept software in the form of preprogrammed chips inserted into slots in the machine. The HP-41CV is more refined, more portable, has more memory space, has more external hardware that can be attached, and can do some clever little tricks that the TI-59 cannot possible do. It should. To get the same basic capabilities, (a card reader and a printer), you may have to spend four times as much for the HP as for the TI with printer. When push comes to shove, as demonstrated by the almost identical duplication of programs for the two machines presented herein, the differences are for the most part cosmetic.

I am making a few assumptions regarding the use of this manual. The first is that the reader has a basic understanding of how his or her calculator works—

how to perform day-to-day calculations, read and write magnetic cards, plug in the printer, locate the "on/off" switch, and the like. The second is that the reader has not tossed his/her owner's manual into the trash. The third is that a printer is part of the reader's equipment. This is *essential*. If no printer is attached, the TI will simply stare at the user, and the HP will hold it's breath and turn blue until one is hooked up.

The TI-59

I like to think of my TI as my workhorse. If I have a simple task to perform that will take fifty or a hundred lines of coding to accomplish, I will always use the TI-59. It has been around since 1977 and even though Texas Instruments has finally given it the deep six, it is still a major role-player in the field of programmable calculators. It prints alpha strings and has indirect registration, several very handy built-in operations, and enough memory to handle just about anything. It uses the Arithmetic Operating System, which simply means that the calculator works by saying "one plus one equals two." Ninety percent of all calculators use this method, so programming can easily be learned.

One of the most useful set of keystrokes uses the OP key. This key is used to print alpha-numeric strings and the combination of string and numeric data. Another series of OP codes adds or subtracts a 1 to a specific data register. This is extremely handy when certain memory registers are used as counters or pointers. OP 18 and 19 test for the presence or absence of an error condition, and set a flag accordingly. OP 08 locates all the labels in a program and prints their locations. OP 10 applies the signum function to a number in the X-register. OP 12 through 15 perform certain statistical and linear interpolation functions. OP 17 reapportions the data register/program space ratio. I use many of the OP codes in my programming, and the reader would be wise to familiarize himself/herself with them.

The TI can use almost all the keys on the keyboard as global labels, except SST, BST, LRN, and one or two others. I use these labels almost exclusively. They may cause the program to run a bit more slowly, and they require an extra step, but they make programming an awful lot easier. Numbers cannot be used as labels. I use the "user" keys A through E and a through e as much as possible because they do not need the prescript SBR or GTO to execute. Most of the time I use A through E keys as auto-execute keys—or "user-interface" keys, to use the computereze. More often than not; A is used for input, B through D are execute keys, and E initializes the program.

I also make use of two other keys on a regular basis. The RST key resets all the flags to "OFF," clears the subroutine return register, and puts the program at Step 000. To program all those functions would be a sizable task, consuming a large chunk of programming space. The CP key clears the test register when encountered in a program. If the reader presses this key when a program is *not* running, all the program steps in memory get sent to a landfill operation somewhere in Hemet, never to return. CP stands for "Clear Program."

The test register is used to test a number to see whether it is equal to or equal-to-or-greater-than whatever is stored in the register. Using the INV key reverses these two operations. But the test register may also be used to store a number that needs to be recalled only once. The user may clear all the memories, clear the current operation, reset the calculator, and even clear out the program memory, and the number in the test register is unaffected. It also saves two steps when used in a program.

A really nice bit of creative programming is the TI's ability to clear out certain blocks of data memory without affecting other blocks. Now, the reader might think that this isn't a particularly remarkable feat, given the calculator's ability to loop, but the task can be performed using only seven program steps. It is done by reapportioning the memory registers. By pressing "5 OP 17, CMS, 6 OP 17," you will clear out all the memory *except* registers 50 through 59. Or by pressing "1 OP 17, CMS, 6 OP 17," you will wipe out only the memory registers 00 through 09. This operation also takes almost no time.

The TI system has only two active registers for arithmetic operations: the X or active register, and the Y or the passive register. I call the Y register the passive register because once the number gets there, nothing in the world can be done to it except to clear the whole operation. The number cannot be changed, recalled, rolled down, or tested. Once the operator key (+, −, ×, ÷) is hit, the Y register is sacrosanct. When a number is in the X register, however, its sign can be changed, it can be inversed, its log taken, its SIN taken, and it can even be stored or summed into a memory register before the = key is hit. These last operations can be very handy in the programming mode.

I prefer to print out all the data, both input and output, with alpha-numeric labels that identify the particular piece of data. This makes checking and quality control easier. However, the task of printing alpha-numerics is cumbersome and space-consuming. To print out a calculated piece of data with a four-character alpha string next to it takes no less than fourteen steps. The number of steps increases if the decimal must be set in a particular mode. It is easy to see that inputting numerous data can eat up a great deal of valuable computing space, severely limiting the labeling of the output data. For this reason, if space is critical, I will use the

by the alpha codes above the key, a holdover from my use of the TI. So when I ask the user to "interface" with the key A, I mean the key in the uppermost left hand corner of the keyboard.

A special word here. I *always* have the USER mode *ON*.

The reader will not find any synthetic programming in this text. This is not because I think there is something wrong with the synthetics that various people have developed. It's just that I have been too lazy to learn the technique. Also, the reader could not duplicate the keystrokes unless he/she had access to certain synthetic software.

The HP has several test functions that the TI does not have. There is no test register because there is no need for one. The functions test between the X and Y registers, or between the X register and zero. Also, there are two flag test functions that are *very* handy: FS?C_ _ and FC?C_ _. The first tests to see whether a flag is set and if so clears the flag, and the second tests to see whether the flag is clear and if *not* clears the flag. This saves the programmer from having to hard-code a clear flag command.

The HP cannot program the SIZE command, so clearing out blocks of memory is not easy. The user can clear out the statistics registers, although to clear out a particular set of registers, a little artful dodging is required to define where the statistics registers are.

The HP41-CV of course uses the Reverse Polish Notation operating system, which has an operational stack with the registers X, Y, Z, and T. Any or all of these may be recalled, stored into, summed into, and used as indirect pointers. Numbers may be hidden in the stack without having to store them in regular registers.

As I have stated before, I use the buffer to print almost all of my data. The usual exception to this is to load the alpha register and use the PRA command. For the buffer, the commands are ACA to accumulate alpha data, ACX to accumulate data from the X register, PRBUF to print the buffer left-justified, and ADV to print the buffer right-justified. I usually try to print the alpha strings in double-spaced letters (with Flag 12 set), and the numeric data I will print with the single-spaced characters (Flag 12 clear). Sometimes I will print special characters using the ACCHR command.

Data can also be stored on magnetic cards in the HP system. The commands for this are WDTA to write data starting with register 00 and including *all* the data registers; WDTAX to write data to a specific set of sequential data registers, denoted in the X register; RDTA to read all the data registers; and RDTAX to read a specific set of sequential data registers, denoted in the X register.

The positioning of the subroutines in the HP is no less critical that in the TI. The HP searches for alpha labels starting at the very *end* of the coding and works its way *backward* through the program. The numeric labels are searched for starting from the command (GTO or EXC), moving forward until the label is found. If the label is *not* found when the end of the coding is reached, the search continues starting at the *beginning* of the program and moving forward. It is therefore advantageous to place subroutines that will be used repeatedly at the *end* of the coding with an alpha label, and branches or hard "GO TO" statements should be accomplished using numeric labels *downstream* of the command. As I said before, certain alpha labels are treated like numerics, and numeric labels 00 through 19 are treated differently from labels 20 through 99. Check the Owner's Manual for these differences.

Where I think of the TI-59 as my 1977 Caprice Classic station wagon, the HP-41CV is my 1984 Audi 5000 S Turbo Coupe. Both accomplish the same thing, but each has its own style. The TI affords simple, direct, no-nonsense programming with almost no hidden glitches. The HP, on the other hand, is complex, powerful, fast, superbly flexible, and very portable. But there is almost always *something* hiding deep within its electronics that is just waiting for the programmer to stumble upon, and the results are not always preferable.

A Word About the Applicable Codes

Several codes cover the design, fabrication, and construction of refineries, chemical plants, cross-country pipelines, and power-generating plants, both nuclear and conventional. In some ways they are different, in some ways the same. Vast committees sit down and decide what stresses should be allowed and how they should be combined, how certain components should be fabricated and what the test procedures are. Most people require cross-training to convert from one code to another.

For the most part, the programs in this text are configured for ASME/ANSI B31.3, Chemical Plant and Petroleum Refinery Piping Code. This volume covers all the piping systems within the defined boundaries of the processing plant. The code is probably the easiest to read and interpret, and the most widely used, in the

TI's ability to store data on a magnetic card to lessen the impact of string labels. The codes for all or most alpha strings are stored on a card and read in when the program is loaded into the program memory. I use registers 30 through 59 for this task, which corresponds to data bank number 3. The reader can find this in the TI-59 User's Manual. If the output data will be printed in a certain order, a loop may be used that references the data memories and the string memories.

Finally, there is the positioning of the subroutines. Because I use global labels for almost everything, there is a certain logic to the way I locate the subroutines in the coding. The TI-59 searches for the label starting at Step 000. A hard-coded "GO TO" statement will transfer control of the program directly to the step number coded, but all label searches begin at the beginning. Therefore, I put all the subroutines at the beginning and the controlling routines or main calculating routines toward the end. Input routines are almost always the first or second routine in the coding. The result of this positioning is that the program takes less time to run. The shorter the search, the faster the execution. The program that demonstrates this the most is the Elastic Center Program, TI-59-1. Because I had to rely so heavily on subroutines, the positioning was critical to reduce the running time. As it is, the execution time is about a minute between members. When the reader looks at the coding for this program, he/she will see that the main controllers are simply series of calls to subroutines.

The HP-41CV

I don't want my readers to get the idea from the preceding that I do not like the HP or that I prefer the TI. Neither is true. If I had to keep one of the systems, it would be the HP. It is more powerful, more portable, has more memory, executes faster, and addresses the alpha-numeric string in a simple, direct, and logical manner. But . . .

I have some gripes about the HP machine. If the program is sizable enough, it may take several seconds for the calculator to enter the programming mode. Rather than simply be ignored, the printer commands will halt execution of a program if the printer is not hooked up. Back-stepping through a program is a major irritation because of the time required, and there are not any of the built-in operations described for the TI. But the biggest fault of the HP system is the way the card reader works.

HP wanted the 41C system to be compatible with its HP-67/97 calculators. Therefore, the magnetic cards carry only sixteen registers, or roughly 112 keystrokes per card side. This means for the Elastic Center Program, which has almost 1750 bytes, takes *nine* cards to store. On the TI, the same analysis, which is only marginally inferior to the HP version, can be stored on four cards. Also, the card reader runs off the battery in the calculator. This wouldn't be bad if it were not that it runs off the battery even when the charger is hooked up. Unfortunately, the charger will not charge as fast as the card reader will drain. If the user has low batteries and wants to load a large program, he/she must wait for the batteries to charge sufficiently to run the card reader. The HP will not load partial programs.

One more gripe before I get to the good stuff. If the card reader, which is also the card *writer*, does not transfer the program correctly to the magnetic cards, the user cannot simply rewrite *that* card. *All* the cards in that program must be rewritten from the beginning. It is for this reason that I do not lightly dump a program from the HP's memory to do a simple task but will instead use the TI.

Except for the above-mentioned problems, the HP-41CV is a dream to use. For the most part, the two calculators speak the same language, so I did not have many problems learning the system. The HP has a much larger vocabulary, owing to the use of the ALPHA mode to spell out those commands that do not appear on the keyboard. Also, the HP can print about 120 alpha-numeric characters, whereas the TI can print only 49. The HP can also build special characters using the 7 × 7 dot matrix printer.

A major programming tool of the HP is the loop commands. ISG and DSE allow the use of one register as both a pointer and a counter. While not as simple as those of the TI, these commands can be used to subtract or add a 1 to a specific register.

The PROMPT key stops the program and displays an alpha string in the calculator display. This "prompts" the user for an input or analysis choice, or a yes/no decision. If the program is to print the prompt string and the corresponding data that is input, I use a trick. Because I almost always print data using the print buffer, I wait until *after* the PROMPT command to accumulate the alpha string into the buffer. The reason is that if the user makes an input error and reinitializes the program, the alpha string is not stuck in the buffer, which will ruin the appearance of the first data printed out after reinitialization.

The HP can make labels out of just about anything. Any alpha string can be used to label a subroutine or a main controller. Any two-digit number from 00 to 99 can also be used, although the way the calculator searches for numeric labels is not as good as the way it searches for alpha labels. There is also a series of special alpha labels that act more like numerics. The reader is encouraged to study the Owner's Manual to get all this straight. In the programs here, I usually call the labels

industry. It contains design for pressure components, including pipe, allowable stress values for metallic and nonmetallic materials, weld reliability factors, strain-related stress range definitions, special precautions for hazardous materials such as anhydrous ammonia and hydrogen sulfide, and stress raiser or stress intensification factors for components. In the Elastic Center Programs, the stress range calculation is based on this code, which translates to some of the other codes but not to others. Specifically, the torsion stress is *not* intensified when added to the bending stress. If the reader is using one of the other codes, the changes to the program can easily be made by the most novice of programmers.

ASME/ANSI B31.4 and ASME/ANSI B31.8 are the two codes that govern the cross-country transportation of liquids and gases in pipelines. They both come under the auspices of the Department of Transportation, which dictates certain design parameters. Where B31.3 uses detailed and extensive tables for the allowable stresses for different materials, the Liquid Petroleum Transportation code (B31.4) and the Gas Transmission code (B31.8) refer to a half-dozen pages that talk about the Specified Minimum Yield Stress, or SMYS. All allowables are based on this number and are qualified with certain reduction factors. B31.8 has population density factors that reduce the allowable as the density increases. As I interpret this, the code committee wants a higher factor of safety for transported gases under pressure for heavily populated areas. It also means that getting away from it all can be hazardous to your health. The allowables are substantially higher than B31.3, and the materials tend to be higher-strength metals. The pipe wall thickness calculations are also based on SMYS, so the pipe walls tend to be thinner. Because the piping may be stressed close to its yield strength, neither code allows support attachments to be welded directly to the pipe, which may leave residual stresses. A full encirclement pad is welded to the pipe and heat treated, and the attachments are welded to the pad. (Simple, huh?) The stress range calculations are the same (torsion stress is *not* intensified), and the stress intensification factors for the components are the same. Pipe wall thickness calculations are slightly different.

Conventional power generating plants and certain areas of nuclear power plants are covered by ASME/ANSI B31.1. This code reads very much like B31.3 but has some distinct differences. Most notable is that in the stress range calculations, the torsion stress *is* intensified along with the bending stresses. Also, the allowables for the same materials are substantially lower. I believe this is because the power generation is usually accomplished using superheated and saturated steam, which has considerable corrosive and erosive effects on steel pipe. By limiting the stress to a value further from the yield point, complications like steam explosions can be avoided. B31.1 is closely linked to ASME Section VIII, the Pressure Boiler code.

ASME Section III covers the design of piping components, piping, pressure connections to vessels, pumps, and so forth that are involved in the design, fabrication, construction, and testing of nuclear power plants. It is the code with which I am the least familiar, so I won't try to discuss its finer points. Subsection NB deals with the Class 1 components, those piping components that come into direct contact with the radioactive material in the core of the plant. The stresses investigated are many and varied, including thermal transients, shock loads, seismic anchor movements, earthquake, support loading, pipe whip (where the piping system breaks loose and tries to take off for Cleveland), and thermal gradients, to name a few. The stresses are all compared against Sm, or what is called the stress intensity. It is measured from the minimum operating condition to the maximum operating condition. The allowables are substantially higher than the other subsections, but the stresses investigated are more complex. The big equations for this section are 9, 10 and 11. Torsion stress is most definitely intensified, along with the bending stress.

Subsection NC covers Class 2 components, critical systems that are not in direct contact with the primary water. This reads very much like the previous subsection, except that the stress allowables are lower. These systems can still cause a great deal of trouble if they fail, so the level of investigation is only slightly less intense.

Finally, Subsection ND covers Class 3 components, which make up the less critical systems. This section looks very familiar to one conversant with B31.3. The stress allowables are lower than B31.3, but the stress range formula is the same, with the exception that the torsion stress is, again, intensified. The intensification factor chart greatly resembles the refinery piping code. The pipe thickness equations are the same, and the pressure reinforcing pad calculations are very similar.

As I stated before, most of the programs are configured for the refinery piping code, but the coding changes can easily be accomplished. I cannot stress the necessity, however, of *thoroughly* testing these changes. In my opinion, B31.3 cuts a kind of middle road between all the other codes. Most of the time, if it satisfies B31.3, it will probably satisfy the others. The nuclear industry demands strict adherence to the equations, however, so any analysis done on the calculator that is to be submitted as the final analysis in this industry should be reconfigured.

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Part I

Piping Flexibility

Chapter 1

Elastic Center Pipe Stress Analysis

Program TI-59-1: Thermal Expansion Analysis of a Two-Anchor Piping System

Introduction:

TI-59-1 is the mating of the Elastic Center method of thermal pipe stress analysis with a state-of-the-art programmable calculator. The program analyzes a two-anchor piping system for thermal expansion or contraction in single or multiple planes. Bend radii at changes of direction, including square corners, can vary throughout the analysis, and anchor movements may be introduced at either anchor. The flexibility matrix may be saved on magnetic cards for reanalysis of one system under varying conditions. The analysis conforms with ASME/ANSI B31.3, 1980.

Nomenclature:

The user inputs the system geometry, pipe size, and thermal conditions to the program. The data consist of the following items:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- E: Modulus of elasticity (Mega psi)
- e: Thermal growth rate (in/100 ft)
- R: Elbow radius (ft)
- K: Elbow flexibility factor
- Dx: Direction code for member input where x is member number:
  - 1 = X-oriented member
  - 2 = Y-oriented member
  - 3 = Z-oriented member
- Lx: Member length, measured to elbow tangents (ft)
- AM: Anchor movements at Anchor 1 consisting of the algebraic difference of the actual movement at Anchor 1 minus the actual movement at Anchor 2, one number for each of the three orthogonal directions (in)
- X: X-coordinate of stress point to be examined (ft)
- Y: Y-coordinate of stress point to be examined (ft)
- Z: Z-coordinate of stress point to be examined (ft)
- I: Stress intensification factor

TI-59-1 is executed in two parts. Part 1 is the geometry input, and Part 2, the equation solver and stress analyzer. A number of keys are used to run the program:

Part 1

- E: To initialize program and input first R and K values
- A: To input direction codes and member lengths
- RST: To input R and K values after the initial set
- R/S: Used in conjunction with the above keys

Part 2

- A: To input OD, T, E, and e
- B: To execute
- E: To input coordinates of stress points
- A′: To execute stress analysis for an X-oriented member
- B′: To execute stress analysis for a Y-oriented member
- C′: To execute stress analysis for a Z-oriented member

Method:

The Elastic Center Method of piping stress analysis, sometimes called the Spielvogel Method, is discussed in great detail in the Grinnell Company's *Piping Design and Engineering*. Some excerpts are included here, but the reader is encouraged to examine the full text for a

complete understanding of the analysis. Basically, the analysis finds the point in each of the three orthogonal planes where the moment in that plane is zero. This point is the "elastic center" of that plane, and each member in the piping system has a moment of inertia and a product inertia with respect to it. When all the moments of inertia and product inertias for each member are summed up, the result, for a three-dimensional system, is a 3 × 3 flexibility matrix.

The matrix may be a simple 3 × 3 because the moments are all zero at the planar elastic centers. Solving with respect to a 1 × 3 displacement matrix results in the three orthogonal system forces. These forces, in conjunction with the developed distances, may be used to calculate the moments and stresses at any point.

When the Elastic Center Method was originally used, modern mainframe computers were unavailable or too costly. Therefore, convenient analysis forms were used to keep all the data straight and to reduce the errors that are a part of manual calculations. Still, a fairly straightforward analysis could consume several hours.

In simplifying the analysis, the forms also greatly limited its capabilities. Because it used the constant C, which is a combination of the thermal growth rate and the modulus of elasticity, the method was limited to metallic pipe at the cold modulus. Also, the method did not easily account for anchor movements.

TI-59-1 allows the user to put back in all the things that had been removed. The modern programmable calculator has numerous memory registers that can separate and remember all the data that would become too cumbersome if the analysis were to be done entirely by hand. Also, today's calculators can perform tens of calculations per second and can thus complete in a matter of minutes an analysis that would take several hours by hand.

Another limitation of the original method has been eliminated.

Originally, the entire system was first analyzed to find the various elastic centers, and then all the inertias were summed with respect to those points. TI-59-1 uses the Luengas Summation System, named for its developer, Carlos E. Luengas. This system sums all the inertias with respect to the point of origin and then transfers the inertias to the elastic centers of each plane after the geometry input is complete. Thus, the calculator does not need to "know" the geometry beforehand.

Anchor movements are also possible with this program. The user may elect to add to the analysis displacements of the two anchors with respect to each other, thereby allowing the user to perform a seismic anchor movement analysis on a system. (This is applicable to static analysis only.)

Finally, the program allows the user to save the summed inertias on a magnetic card. This step is somewhat similar to saving the decomposed stiffness matrix in a major mainframe program. It allows the user to reanalyze the same system for various combinations of anchor movement and/or various thermal conditions without having to reinput the geometry each time.

Accuracy was measured against the same geometry and thermal conditions analyzed by a major mainframe stiffness matrix method. The results follow:

	TI-59-1	MAINFRAME ANALYSIS
Fx	2823 #	2533 #
Fy	−1520 #	−1385 #
Fz	161 #	132 #
@ A1		
Mx	8330 ft-lb	8010 ft-lb
My	13,941 ft-lb	13,575 ft-lb
Mz	−1791 ft-lb	−1546 ft-lb
@ A2		
Mx	−8896 ft-lb	−8631 ft-lb
My	−15,533 ft-lb	−15,127 ft-lb
Mz	−3306 ft-lb	−2821 ft-lb
Maximum stress		
	1180 psi (ST)	1107 psi (ST)
	12,779 psi (SB)	12,434 psi (SB)
	12,995 psi (SE)	12,596 psi (SE)

Limitations:

The program is set up to handle any number of members, but only two anchors. There is no provision for intermediate supports. Fully fixed rigid anchors are assumed. Only English units may be used. The program will only analyze one pipe size and schedule at a time. Colinear members will not be analyzed correctly. The analysis does not include dead weight or internal pressure.

A Word About Modeling:

Obviously, not all piping systems will be routed with only two anchors. TI-59-1 is a tool to be used by the analyst. Complex systems must be broken down into small sections, from support to support, and combined as a whole by the analyst by manipulating the thermal conditions and anchor movements to best simulate the real situation. Many iterations and analyses may be necessary.

Special Note:

When performing the stress analysis at various points in the system, the user should be alert to the signs of the moments that are printed. At the first anchor, the moments will have the *correct* sign. At the second anchor, the moments will be printed with the *opposite* signs from what is the case. At all points in between, the moments *may* or *may not* have the correct sign. This is because, given the limitations of program space in the TI-59, the program does not "know" which side of the elastic center the point is on. Analysts are cautioned to use their best judgment when determining the sign of intermediate moments.

User Instructions

Program Number TI-59-1 **Title** Elastic Center Part 1

Step	Instructions	Input	Keystroke			Display
1	Reapportion the calculator's memory proportions.	4	2nd	OP	17	639.39
2	Read in magnetic cards for Part 1 (two cards).					
3	Initialize program and input radius of the first elbow (R1).	R1	E			R1
4	Input the K factor for the first elbow (K1).	K1	R/S			K1
5	Input the direction code for the first member (D1).	D1	A			D1
6	Input the member length of the first member (L1).	L1	R/S			0.
7	Input radius of next elbow.	Rx	RST	R/S		Rx
8	Input K factor for the next elbow.	Kx	R/S			Kx
	Note: If the next elbow has the same data as the last, skip to Steps 7 and 8.					
9	Input the next direction code (Dx).	Dx	A			Dx
10	Input the next member length (Lx).	Lx	R/S			0.
	Repeat Steps 7 to 10 for each member that follows, skipping the R and K values where applicable. When the final data has been input and the coordinates of the next-to-last point have been printed, proceed to the following steps.					
11	Complete analysis.		R/S			0.
12	Record the data onto magnetic cards. (This step may be skipped.)	4	2nd	WRITE		4.
13	Read in cards for Part 2.					
14	Input OD.	OD	A			OD
15	Input T.	T	A			T
16	Input E.	E	A			E
17	Input e.	e	A			e
18	Continue analysis.		B			0.
19	Input X-anchor movement.	X-AM	R/S			Total delta X
20	Input Y-anchor movement.	Y-AM	R/S			Total delta Y
21	Input Z-anchor movement.	Z-AM	R/S			Fz
22	Input X-coordinate.	X	E			X
23	Input Y-coordinate.	Y	R/S			Y
24	Input Z-coordinate.	Z	R/S			Z
25	Choose orientation.	X-orientation	2nd	A		
		Y-orientation	2nd	B		
		Z-orientation	2nd	C		
						I (offered)
26	Input I factor needed.	I	R/S			SE
	Note: If the I factor offered is correct, only press R/S.					
	Repeat Steps 22 through 26 for all points where moments and stresses are desired.					
	Note: To reanalyze a system using the data stored on magnetic cards:					
27	Read in cards for Part 2.					
28	Read in data card.					
29	Go to Step 14.					

Data Register Contents

REGISTER	DATA	REGISTER	DATA
00	IND	30	L2; OD
01	Lxy; Xi	31	D2; T
02	Lx; $\bar{x}$; Yi	32	Used; E
03	Ly; $\bar{y}$; Zi	33	L (straight); e
04	Ixy; IND	34	**(.149) (K or 1.15) (R^3);** $\bar{x}$ (xy)
05	Ix (xy); IND	35	(π/2) (K or 1.15) (R); $\bar{y}$ (xy)
06	Iy (xy); IND	36	IND; $\bar{x}$ (xz)
07	Lxz; Sx	37	IND; $\bar{z}$ (xz)
08	Lx; $\bar{x}$; Ix; Sy	38	IND; $\bar{y}$ (yz)
09	Lz; $\bar{z}$; Ixy Sz	39	IND; $\bar{z}$ (yz)
10	Ixz; Ixz		
11	Ix (xz); Ixy		
12	Iz (xz); Iy		
13	Lyz; Iyz		
14	Ly; $\bar{y}$; Ixz		
15	Lz; $\bar{z}$; Iyz		
16	Iyz; Iz		
17	Iy (yz)		
18	Iz (yz)		
19	$\bar{x}$		
20	$\bar{y}$; Fx		
21	$\bar{z}$; Fy		
22	R (next) Fz		
23	K (next); developed L, Y		
24	Developed length, Z		
25	R (this); developed L, X		
26	E1#; I pipe; Mx		
27	K (this); My		
28	L1; Mz		
29	D1; i (last elbow)		

The following data must be stored in memory before the cards for Part 2 are recorded.

Data	Register #
3216	30
37	31
17	32
54	33

TI-59-1 Input Sheet

INDEX OF TERMS

R: Elbow radius (ft)

K: Elbow flexibility factor

D: Direction code for member input
1 = X-member
2 = Y-member
3 = Z-member

L: Member length (ft)

X: Point coordinate in the X-direction (ft)

Y: Point coordinate in the Y-direction (ft)

Z: Point coordinate in the Z-direction (ft)

*: End-of-data flags

4.167 2.44	R K	Elbow radius and K factor for elbow at Point 2
2. 8.	D L	Direction code and member length for Member 1
1.25 8.15	R K	Elbow radius and K factor for elbow at Point 3
3. 18.	D L	Direction code and member length for Member 2
0. 8. 0.	X Y Z	Coordinates at Point 2
4.167 2.44	R K	Elbow radius and K factor for elbow at Point 4
-1. 14.	D L	Direction code and member length for Member 3
0. 8. 18.	X Y Z	Coordinates at Point 3
-2. 20.	D L	Direction code and member length for Member 4
-14. 8. 18.	X Y Z	Coordinates at Point 4
* *		
-14. -12. 18.	X Y Z	Coordinates at Point 5

TI-59-1 Output Sheet 1

10.75	OD	Pipe outside diameter (in)
0.365	T	Pipe wall thickness (in)
27.9	E	Modulus of elasticity (Mega psi)
6.17	e	Thermal growth rate (in/100 ft)
.0000000081		Inertia matrix determinant
0.		X-anchor movement (in)
-0.8638		Total delta X between anchors (in)
0.		Y-anchor movement (in)
-0.7404		Total delta Y between anchors (in)
0.		Z-anchor movement (in)
1.1106		Total delta Z between anchors (in)
894.	FX	Applied at Anchor 1 (lb)
571.	FY	Applied at Anchor 1 (lb)
-962.	FZ	Applied at Anchor 1 (lb)

The inertia matrix determinant is printed automatically by the Master Library Software program, used by the program (ML-02).

The anchor movements input by the user represent the total algebraic difference between the movement at Anchor 1 and the movement at Anchor 2.

Example: Anchor 1 moves 0.25″ in the *positive* X-direction.
Anchor 2 moves 0.10″ in the *negative* X-direction.

The anchor movement that the user inputs is:

$$0.25 - (-0.10) = 0.35''$$

If the movement at Anchor 2 had been 0.5″ *positive*, the user input would be:

$$0.25 - 0.50 = -0.25''$$

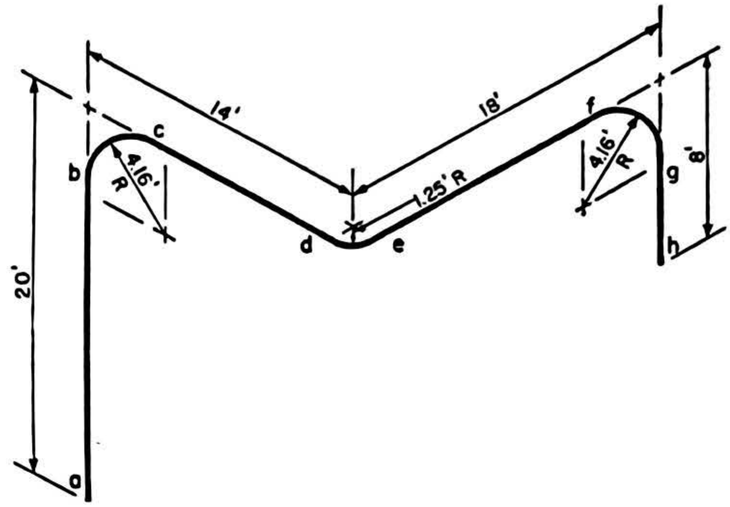
TI-59-1 Output Sheet 2

0.	X-coordinate (ft)	-1.25
0.	Y-coordinate (ft)	8.
0.	Z-coordinate (ft)	18.
Y	Orientation flag	X
-10961.	Mx (ft-lb)	7017.
7057.	My (ft-lb)	-7832.
-7786.	Mz (ft-lb)	80.
1.168 I	I factor (offered)	1.168 I
1.000 I	I factor (used)	2.610 I
1416.	Torsion stress	1408.
5395.	Bending stress	8204.
6093.	Stress range	8673.
-14.	X-coordinate (ft)	0.
-12.	Y-coordinate (ft)	8.
18.	Z-coordinate (ft)	0.
Y	Orientation flag	Y
-12223.	Mx (ft-lb)	-3265.
4433.	My (ft-lb)	7057.
-10517.	Mz (ft-lb)	-635.
1.168 I	I factor (offered)	1.168 I
1.000 I	I factor (used)	1.168 I
889.	Torsion stress	1416.
6471.	Bending stress	1559.
6711.	Stress range	3233.
0.	X-coordinate (ft)	
8.	Y-coordinate (ft)	
16.75	Z-coordinate (ft)	
Z	Orientation flag	
6303.	Mx (ft-lb)	
-7917.	My (ft-lb)	
-635.	Mz (ft-lb)	
1.168 I	I factor (offered)	
2.610 I	I factor (used)	
127.	Torsion stress	
10599.	Bending stress	
10602.	Stress range	

The moments at Anchor 1 (0, 0, 0) will have the *correct* sign.
The moments at Anchor 2 (last point) will have the *opposite* sign.

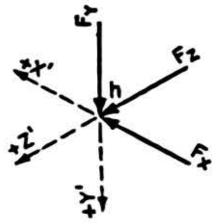
Source Documentation

MULTIPLE PLANE SYSTEM CONTAINING CIRCULAR ARCS



Bend $R = 5D_n = 4.16'$

L.R.Ell $R = 1.5D_n = 1.25'$



Given: A 10 inch piping system in accordance with the sketch shown above.

Maximum Operating Pressure P	350 psi
Maximum Operating Temperature	750° F
Piping Specification	A.S.T.M. A-106 Grade A

Data:

$t = 0.365$ inches = schedule 40 — page 2 and 14

$d = 10.02$ inches
$I_P = 160.8$ inches^4
$S_m = 29.9$ inches^3
$A_I = 78.9$ inches^2
$A_M = 11.91$ inches^2
$k_{bend} = 2.44$
$i_{bend} = 1.17$
$k_{elbow} = 8.15$
$i_{elbow} = 2.61$
— page 14

$c_{at\ 750°} = 996$ — page 11

Allow. $S_A = 17{,}675$ psi — page 3

Find: Reaction forces F_x, F_y and F_z at point h (at point a reaction forces equal and opposite).

Reaction moments M_{xy}, M_{xz} and M_{yz} at points a and h. Amount and location of Maximum Combined Stress, s.

Solution: Project the piping system into the three planes, determine the location of the centroid and calculate the line inertias in the same manner as outlined on page 56. except that the flexibility factor, k, must be included for all curved segments in the plane of projection.

$$\text{Total } I_x = 1993 + 3283 = 5276 \text{ ft}^3$$
$$\text{Total } I_y = 2802 + 3841 = 6643 \text{ ft}^3$$
$$\text{Total } I_z = 3091 + 1978 = 5069 \text{ ft}^3$$

$$I_{xy} = 1334 \text{ ft}^3$$
$$I_{xz} = 1774 \text{ ft}^3$$
$$I_{yz} = 706 \text{ ft}^3$$

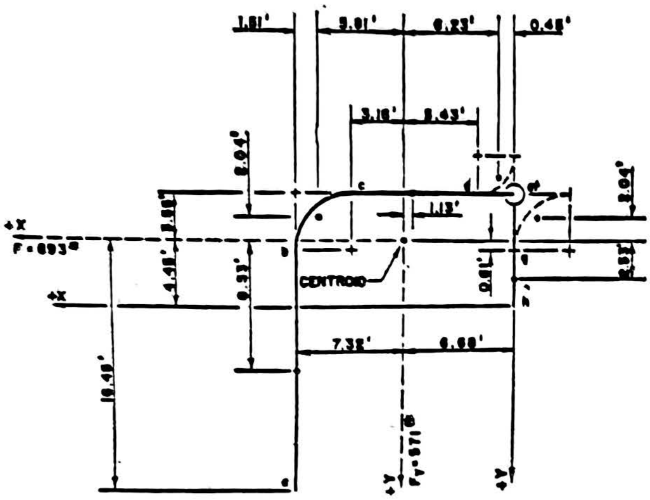
$$L_x c I_P = 14 \times 996 \times 160.8 = 2{,}242{,}195 \text{ lb ft}^3$$
$$L_y c I_P = 12 \times 996 \times 160.8 = 1{,}921{,}882 \text{ lb ft}^3$$
$$L_z c I_P = 18 \times 996 \times 160.8 = 2{,}882{,}822 \text{ lb ft}^3$$

(1) $F_x\,5278 - F_y\,1400 - F_z\,1779 = 2{,}242{,}195$

(2) $-F_x\,1400 + F_y\,6643 - F_z\,706 = 1{,}921{,}882$

(3) $-F_x\,1779 - F_y\,706 + F_z\,5069 = 2{,}882{,}822$

PROJECTION IN XY PLANE



To find c.g. of each segment see page 44.

Lengths:

$ab = 15.84'$
$cd = 8.59'$
$ef = 12.59'$
$gh = 3.84'$

Radii:

$bc - R = 4.16'$
$de - R = 1.25'$
$fg - R = 4.16'$

Centroid (calculated with origin at point h)

	Eq. No.	Length L, Ft	x'	Lx'	y'	Ly'
ab	I	15.84	+14	+222.0	+4.08	+ 64.6
bc	III	$1.57 \times 2.44 \times 4.16 = 15.94$	+12.49	+199.1	−6.49	−103.5
cd	I	8.59	+ 5.55	+ 47.7	−8	− 68.7
de	V	$1.81 \times 1.25 = 2.26$	+ 0.45	+ 1.0	−8	− 18.1
ef	II	$1.3 \times 12.59 = 16.35$	0	0	−8	−130.8
fg	V	$1.81 \times 4.16 = 7.54$	0	0	−6.49	− 48.9
gh	I	3.84	0	0	−1.92	− 7.4
		$\Sigma L = 70.36$		$\Sigma Lx' = 469.8$		$\Sigma Ly' = -312.8$

$$\bar{x} = \frac{+469.8}{70.36} = +6.68 \text{ ft} \qquad \bar{y} = \frac{-312.8}{70.36} = -4.45 \text{ ft}$$

I_{xy}

ab	VI	$15.84 \times 7.32 \times 8.53$	= + 989
bc	X B	$+2.44(0.137 \times 4.16^2) + 1.57 \times 2.44 \times 4.16 \times 5.81(-2.04)$	= − 165
cd	VI	$8.59(-1.13)(-3.55)$	= + 34.4
de	XI	$1.81 \times 1.25(-6.23)(-3.55)$	= + 50.0
ef	VIII	$1.3 \times 12.59(-6.68)(-3.55)$	= + 388.0
fg	XI	$1.81 \times 4.16(-6.68)(-2.04)$	= + 102.5
gh	VI	$3.84(-6.68)(2.53)$	= − 64.9
			I_{xy} = +1334

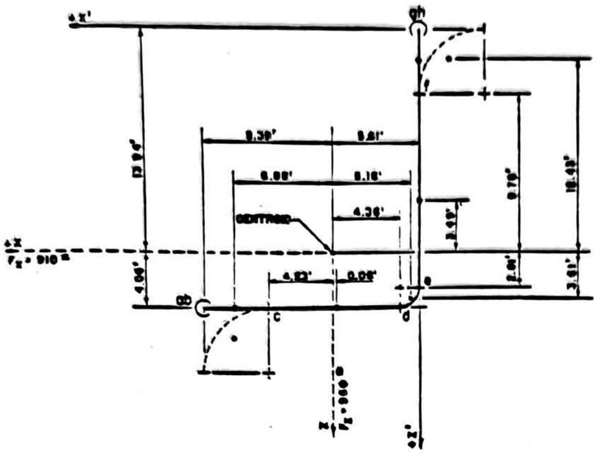
I_x

ab	XIV B	$\frac{(15.84)^3}{12} + 15.84(8.53)^2$	= 1484
bc	XVII A	$2.44(0.149 \times 4.16^3) + 1.57 \times 2.44 \times 4.16(2.04)^2$	= 92.5
cd	XIV A	$8.59(3.55)^2$	= 108.3
de	XVIII A	$1.81 \times 1.25(3.55)^2$	= 28.5
ef	XVI	$1.3 \times 12.59(3.55)^2$	= 206.3
fg	XVIII B	$1.15(0.149 \times 4.16^3) + 1.81 \times 4.16(2.04)^2$	= 43.7
gh	XIV B	$\frac{(3.84)^3}{12} + 3.84(2.53)^2$	= 29.3
			I_x = 1993

I_y

ab	XIV A	$15.84(7.32)^2$	= 849
bc	XVII B	$2.44(0.149 \times 4.16^3) + 1.57 \times 2.44 \times 4.16(5.81)^2$	= 564
cd	XIV B	$\frac{(8.59)^3}{12} + 8.59(1.13)^2$	= 63.8
de	XVIII B	$1.15(0.149 \times 1.25^3) + 1.81 \times 1.25(6.23)^2$	= 88.1
ef	XVI	$1.3 \times 12.59(6.68)^2$	= 730
fg	XVIII A	$1.81 \times 4.16(6.68)^2$	= 336
gh	XIV A	$3.84(6.68)^2$	= 171
			I_y = 2802

PROJECTION IN XZ PLANE



To find c.g. of each segment see page 44.

Lengths:

$ab = 15.84'$
$cd = 8.59'$
$ef = 12.59'$
$gh = 3.84'$

Radii:

$bc - R = 4.16'$
$de - R = 1.25'$
$fg - R = 4.16'$

Centroid (calculated with origin at point h)

	Eq. No.	Length L, Ft	z'	Lz'	x'	Lx'
ab	II	1.3 × 15.84 = 20.60	+14	+288	+18	+ 371
bc	V	1.81 × 4.16 = 7.54	+12.49	+ 94.1	+18	+ 135.8
cd	I	8.59	+ 5.55	+ 47.7	+18	+ 154.8
de	III	1.57 × 8.15 × 1.25 = 16.00	+ 0.45	+ 47.2	+17.55	+ 280.8
ef	I	12.59	0	0	+10.46	+ 131.8
fg	V	1.81 × 4.16 = 7.54	0	0	+ 1.51	+ 11.4
gh	II	1.3 × 3.84 = 4.99	0	0	0	0
		ΣL = 77.85		$\Sigma Lz'$ = +437.0		$\Sigma Lx'$ = +1085.6

$$\bar{z} = \frac{437.0}{77.85} = +5.61 \text{ ft} \qquad \bar{x} = \frac{1085.6}{77.85} = +13.94 \text{ ft}$$

I_{xz}

	Eq. No.		
ab	VIII	1.3 × 15.84 × 8.39 × 4.06	+ 701
bc	XI	1.81 × 4.16 × 6.88 × 4.06	+ 210
cd	VI	8.59(−.06)4.06	− 2.1
de	X B	8.15(0.137 × 1.25²) + 1.57 × 8.15 × 1.25(−5.16)(3.61)	− 296
ef	VI	12.59(−5.61)(−3.49)	+ 246
fg	XI	1.81 × 4.16(−5.61)(−12.43)	+ 525
gh	VIII	1.3 × 3.84(−5.61)(−13.94)	+ 390
		I_{xz} =	+1774

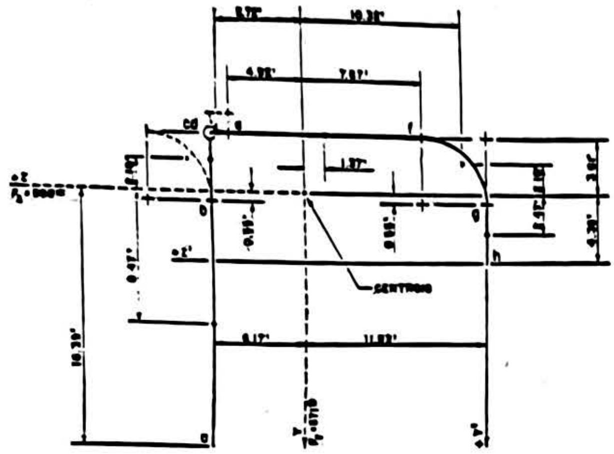
I_x

	Eq. No.		
ab	XVI	$1.3 \times 15.84(4.06)^2$	340
bc	XVIII A	$1.81 \times 4.16(4.06)^2$	124
cd	XIV A	$8.59(4.06)^2$	142
de	XVII A	$8.15(0.149 \times 1.25^3) + 1.57 \times 8.15 \times 1.25(3.61)^2$	211
ef	XIV B	$\frac{(12.59)^3}{12} + 12.59(3.49)^2$	320
fg	XVIII B	$1.15(0.149 \times 4.16^3) + 1.81 \times 4.16(12.43)^2$	1176
gh	XVI	$1.3 \times 3.84(13.94)^2$	970
		I_x =	3283

I_z

	Eq. No.		
ab	XVI	$1.3 \times 15.84(8.39)^2$	1450
bc	XVIII B	$1.15(0.149 \times 4.16^3) + 1.81 \times 4.16(6.88)^2$	369
cd	XIV B	$\frac{(8.59)^3}{12} + 8.59(.06)^2$	53
de	XVII B	$8.15(0.149 \times 1.25^3) + 1.57 \times 8.15 \times 1.25(5.16)^2$	429
ef	XIV A	$12.59(5.61)^2$	396
fg	XVIII A	$1.81 \times 4.16(5.61)^2$	237
gh	XVI	$1.3 \times 3.84(5.61)^2$	157
		I_z =	3091

PROJECTION IN YZ PLANE



To find c.g. of each segment see page 44.

Lengths:

$ab = 15.84'$
$cd = 8.59'$
$ef = 12.59'$
$gh = 3.84'$

Radii:

$bc - R = 4.16'$
$de - R = 1.25'$
$fg - R = 4.16'$

Centroid (calculated with origin at point *h*)

	Eq. No.	Length L, Ft	y'	Ly'	z'	Lz'
ab	I	15.84	+4.08	+ 64.6	+18	285.5
bc	V	$1.81 \times 4.16 = 7.54$	−6.49	− 48.9	+18	135.8
cd	II	$1.3 \times 8.59 = 11.18$	−8	− 89.5	+18	201.5
de	V	$1.81 \times 1.25 = 2.26$	−8	− 18.1	+17.55	39.7
ef	I	12.59	−8	−100.8	+10.46	131.7
fg	III	$1.57 \times 2.44 \times 4.16 = 15.94$	−6.49	−103.5	+ 1.51	24.1
gh	I	3.84	−1.92	− 7.4	0	0
		$\Sigma L = 69.19$		$\Sigma Ly' = -303.6$		$\Sigma Lz' = 818.3$

$$\bar{y} = \frac{-303.6}{69.19} = -4.39 \text{ ft} \qquad \bar{z} = \frac{818.3}{69.19} = +11.83 \text{ ft}$$

I_{yz}

	Eq. No.		
ab	VI	$15.84 \times 8.47 \times 6.17$	$= +\ 827.7$
bc	XI	$1.81 \times 4.16(-2.10) \times 6.17$	$= -\ 97.7$
cd	VIII	$1.3 \times 8.59(-3.61) \times 6.17$	$= -\ 249$
de	XI	$1.81 \times 1.25(-3.61) \times 5.72$	$= -\ 46.7$
ef	VI	$12.59(-3.61)(-1.37)$	$= +\ 62.3$
fg	X A	$-2.44(0.137 \times 4.16^2) + 1.57 \times 2.44 \times 4.16(-2.10)(-10.32)$	$= +\ 321.4$
gh	VI	$3.84 \times 2.47(-11.83)$	$= -\ 112$
			$I_{yz} = +\ 706$

I_y

	Eq. No.		
ab	XIV A	$15.84(6.17)^2$	$= 603$
bc	XVIII A	$1.81 \times 4.16(6.17)^2$	$= 287$
cd	XVI	$1.3 \times 8.59(6.17)^2$	$= 426$
de	XVIII B	$1.15(0.149 \times 1.25^3) + 1.81 \times 1.25(5.72)^2$	$= 74$
ef	XIV B	$\frac{(12.59)^3}{12} + 12.59(1.37)^2$	$= 190$
fg	XVII B	$2.44(0.149 \times 4.16^3) + 1.57 \times 2.44 \times 4.16(10.32)^2$	$= 1724$
gh	XIV A	$3.84(11.83)^2$	$= 537$
			$I_y = 3841$

I_z

	Eq. No.		
ab	XIV B	$\frac{(15.84)^3}{12} + 15.84(8.47)^2$	$= 1468$
bc	XVIII B	$1.15(0.149 \times 4.16^3) + 1.81 \times 4.16(2.10)^2$	$= 46$
cd	XVI	$1.3 \times 8.59(3.61)^2$	$= 146$
de	XVIII A	$1.81 \times 1.25(3.61)^2$	$= 29.5$
ef	XIV A	$12.59(3.61)^2$	$= 164.0$
fg	XVII A	$2.44(0.149 \times 4.16^3) + 1.57 \times 2.44 \times 4.16(2.10)^2$	$= 96.5$
gh	XIV B	$\frac{(3.84)^3}{12} + 3.84(2.47)^2$	$= 23$
			$I_z = 1973$

SOLUTION OF EQUATIONS

Line	F_x	F_y	F_z	Constant		Line
(1)	+5276	−1334	−1774	−2,242,195		(1)
(4)	−1	+0.253	+0.336	+425		(4)
(2)	−1334	+6643	−706	−1,921,882		(2)
(5)	+1334	−337	−449	−567,275		(5)
(6)	0	+6306	−1155	−2,489,157		(6)
(7)		−1	+0.183	+395		(7)
(3)	−1774	−706	+5069	−2,882,322		(3)
(8)	+1774	−449	−596	−753,378		(8)
(9)		+1155	−211	−455,516		(9)
(10)	0	0	+4262	−4,091,716		(10)
(11)			−1	+960		(11)
(11A)			$-F_z$	+960 =	0	(11A)
(11B)			F_z =	+960 =	+960	(11B)
(7A)		$-F_y$	+0.183 × 960	+395 =	0	(7A)
(7B)		F_y =	+176	+395 =	+571	(7B)
(4A)	$-F_x$	+0.253 × 571	+0.336 × 960	+425 =	0	(4A)
(4B)	F_x =	+144	+323	+425 =	+893	(4B)

$F_x = 893$ lb $\qquad F_y = 571$ lb $\qquad F_z = 960$ lb

MOMENTS IN FOOT POUNDS

	XY Plane	XZ Plane	YZ Plane
a	+893 × 16.45 − 571 × 7.32 = +10,510	+893 × 4.06 − 960 × 8.39 = −4429	−571 × 6.17 + 960 × 16.39 = +12,211
	$M = \sqrt{(10{,}510)^2 + (12{,}211)^2} = 16{,}111$ $\quad T_s = 4429$		
b	+893 × 0.61 − 571 × 7.32 = −3635	Same as *a* = −4429	−571 × 6.17 + 960 × 0.55 = −2995
	$M = \sqrt{(3635)^2 + (2995)^2} = 4710$ $\quad T_s = 4429$		
c	−893 × 3.55 − 571 × 3.16 = −4974	+893 × 4.06 − 960 × 4.23 = −435	−571 × 6.17 − 960 × 3.61 = −6989
	$M = \sqrt{(4974)^2 + (435)^2} = 4993$ $\quad T_s = 6989$		
d	−893 × 3.55 + 571 × 5.43 = −70	+893 × 4.06 + 960 × 4.36 = +7811	Same as *c* = −6989
	$M = \sqrt{(7811)^2 + (70)^2} = 7811$ $\quad T_s = 6989$		
e	−893 × 3.55 + 571 × 6.68 = +644	+893 × 2.81 + 960 × 5.61 = +7895	−571 × 4.92 − 960 × 3.61 = −6275
	$M = \sqrt{(7895)^2 + (6275)^2} = 10{,}085$ $\quad T_s = 644$		
f	Same as *e* = +644	−893 × 9.78 + 960 × 5.61 = −3348	+571 × 7.67 − 960 × 3.61 = +914
	$M = \sqrt{(3348)^2 + (914)^2} = 3471$ $\quad T_s = 644$		
g	+893 × 0.61 + 571 × 6.68 = +4359	−893 × 13.94 + 960 × 5.61 = −7063	+571 × 11.83 + 960 × 0.55 = +7283
	$M = \sqrt{(4359)^2 + (7283)^2} = 8488$ $\quad T_s = 7063$		
h	+893 × 4.45 + 571 × 6.68 = +7788	Same as *g* = −7063	+571 × 11.83 + 960 × 4.39 = +10,969
	$M = \sqrt{(7788)^2 + (10{,}969)^2} = 13{,}453$ $\quad T_s = 7063$		

I. From inspection the maximum bending moment, M, is 16,111 ft lb occurring at point a which is straight pipe. The accompanying torque T is 4429 ft lb.

II. The maximum torque T is 6989 ft lb in line cd and the larger accompanying bending moment, M, is 7811 ft lb at point d which is curved pipe with an i factor of 2.61.

III. The maximum bending moment, M, in curved pipe with an i factor of 2.61 is 10,085 ft lb at point e with an accompanying torque T of 644 ft lb.

IV. The bending moments in curved pipe with an i factor of 1.17 are relatively small (points b, c, f, and g) and therefore need not be considered.

The maximum expansion stress is determined in the manner outlined on page 3 as follows:

Case I (at point a)

$$M = 16{,}111 \text{ ft lb} = 16{,}111 \times 12 = 193{,}332 \text{ inch pounds}$$

$$T = 4429 \text{ ft lb} = 4429 \times 12 = 53{,}148 \text{ inch pounds}$$

$$s_B = \frac{M}{S_m} = \frac{193{,}332}{29.9} = 6466 \text{ psi}$$

$$s_T = \frac{T}{2S_m} = \frac{53{,}148}{2 \times 29.9} = 889 \text{ psi}$$

$$s_E = \sqrt{(s_B)^2 + 4(s_T)^2} = \sqrt{(6466)^2 + 4(889)^2} = 6706 \text{ psi}$$

Case II (at point d)

$$M = 7811 \text{ ft lb} = 7811 \times 12 = 93{,}732 \text{ inch pounds}$$

$$T = 6989 \text{ ft lb} = 6989 \times 12 = 83{,}868 \text{ inch pounds}$$

$$s_B = \frac{M}{S_m} i = \frac{93{,}732}{29.9} \times 2.61 = 8182 \text{ psi}$$

$$s_T = \frac{T}{2S_m} = \frac{83{,}868}{2 \times 29.9} = 1402 \text{ psi}$$

$$s_E = \sqrt{(s_B)^2 + 4(s_T)^2} = \sqrt{(8182)^2 + 4(1402)^2} = 8649 \text{ psi}$$

Case III (at point e)

$$M = 10{,}085 \text{ ft lb} = 10{,}085 \times 12 = 121{,}020 \text{ inch pounds}$$

$$T = 644 \text{ ft lb} = 644 \times 12 = 7728 \text{ inch pounds}$$

$$s_B = \frac{M}{S_m} i = \frac{121{,}020}{29.9} \times 2.61 = 10{,}564 \text{ psi}$$

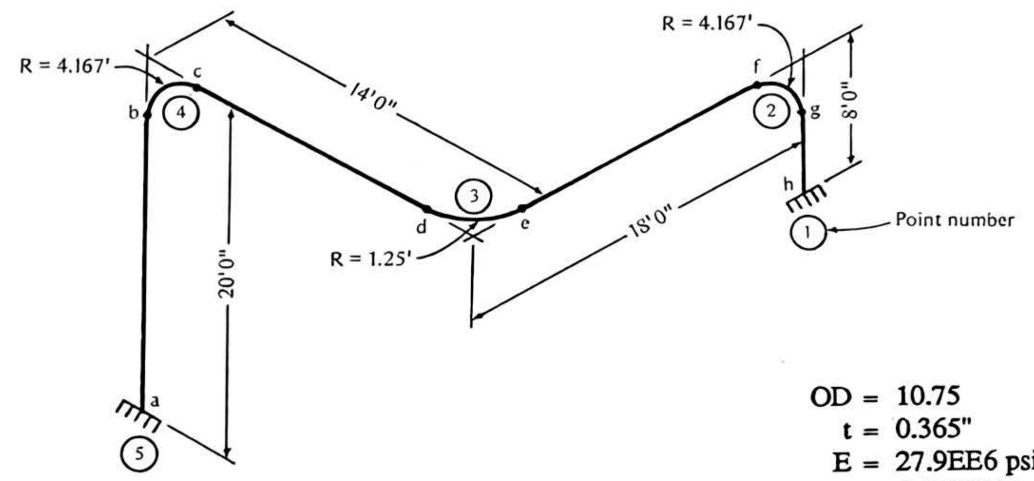
$$s_T = \frac{T}{2S_m} = \frac{7728}{2 \times 29.9} = 129 \text{ psi}$$

$$s_E = \sqrt{(s_B)^2 + 4(s_T)^2} = \sqrt{(10{,}564)^2 + 4(129)^2} = 10{,}567 \text{ psi}$$

The maximum expansion stress s_E is 10,567 psi, occurring at point c, and is less than the allowable stress range S_A of 17,675 psi.

Sample Problem

Program: TI-59-1



OD = 10.75
t = 0.365"
E = 27.9EE6 psi
e = 6.17"/100'

Step	Input	Key Stroke	Display	Printer		Comments
				PART ONE		
1	4.167	E	4.167	4.167	R	Stores R in R22.
2	2.44	R/S	2.44	2.44	K	Stores K in R23.
3	2	A	2.	2.	D	Stores D1 in R31.
4	8	R/S	0.			Stores L1 in R30, sets all pointers for a Y-member. Calculates the elbow identifier and stores it in R26. Sets the pointers for the first member in the "last" member registers. The program always operates on the member previously input. In this case, there is no previous member, so no calculations are performed. The values for R and K are taken from "this" member registers (R22 and R23) and moved to "last" member registers (R25 and R27).
5	1.25	RST:R/S	1.25	1.25	R	Stores R in R22.
6	8.15	R/S	8.15	8.15	K	Stores K in R23.
7	3	A	3.	3.	D	Stores D2 in R31.
8	18	R/S	0.	18.	L	Stores L2 in R30, sets all pointers for a Z-member. Calculates the elbow identifier and stores it in R26. Performs all the summations for Member 1 (a Y-member from g to h on the sketch) and the first bend (a Y-to-Z elbow from f to g). Rolls all pointers for "this" member data to "last" member registers. Prints the coordinates at Point 2.
				0.	X	
				8.	Y	
				0.	Z	

Step	Input	Key Stroke	Display	Printer		Comments
9	4.167	RST: R/S	4.167	4.167	R	Store R in R22.
10	2.44	R/S	2.44	2.44	K	Store K in R23.
11	-1	A	-1	-1.	D	Store D3 in R31.
12	14	R/S	0.	14. 0. 8. 18.	L X Y Z	Store L3 in R30, sets all pointers for an X-member. Calculates the elbow identifier and stores it in R26. Performs all the summations for Member 2 (a Z-member) from e to f) and the second bend (a Z-to-X elbow from d to e). Rolls all pointers for "this" member data to "last" member registers. Prints the coordinates at Point 3.
13	-2	A	-2.	-2.	D	Stores D4 in R31.
14	20	**R/S**	0.	20. -14. 8. 18.	L X Y Z	Stores L4 in R30, sets all pointers for a Y-member. Same process as above for Member 3 (an X-member from c to d) and the third bend (an X-to-Y elbow from b to c). Prints the coordinates at Point 4.
15		R/S	0.	* *		Prints the end of data flags. Sets Flag 1 and clears the elbow identifier.
16				-14 -12 18	X Y Z	As in the case of the first member, this last step will cause the program to skip the elbow routines. The summations are performed for the member from a to b. The final developed distances are stored in R25 (X), R23 (Y), and R24 (Z), for the calculations in Part 2.
				PART TWO		
17	10.75	A	10.75	10.75	OD	Stores OD in R30.
18	.365	A	0.365	0.365	T	Stores T in R31.
19	27.9	A	27.9	27.9	E	Stores E in R32.
20	6.17	A	6.17	6.17	e	Stores e in R33.
21		B	0.	.0000000081		The program prints the matrix determinant and stops for the input of any anchor movements in any of the three directions. The total deflection in each direction is printed after the anchor movement. The matrix is solved and the system forces are printed.
22		R/S	0.	0. -0.8638		
23		R/S	0.	0. -0.7404		
24		R/S	-962.	0. 1.1106 894. 571. -962.	 FX FY FZ	
25	0	E	0.	0.		X-coordinate is stored in R01.
26	0	R/S	0.	0.		Y-coordinate is stored in R02.
27	0	R/S	0.	0.		Z-coordinate is stored in R03.
28		2nd: B	1.168	Y -10961. 7057. -7786. 1.168	 I	The moments at Point 1 are calculated and printed. The I factor for the last elbow entered in memory is printed.
29	1	R/S	6093.	1.000 1416. 5395. 6093.	I	The user-input I value is printed and the torsion, bending, and range stresses are printed, in that order.

Step	Input	Key Stroke	Display	Printer		Comments
30	-14	E	-14.	-14.		Steps 30 through 49 calculate the moments and stresses at a, e, d, and Point 2, in that order. As stated in the program description, the moments at a (Point 5) are printed with the signs reversed because of the program's inability to tell on which side of the elastic center the input point is.
31	-12	R/S	-12.	-12.		
32	18	R/S	18.	18.		
33		2nd: B	1.168	Y		
				-12223.		
				4433.		
				-10517.		
				1.168	I	
34	1	R/S	6711.	1.000	I	
				899.		
				6471.		
				6711.		
35	0	E	0.	0.		
36	8	R/S	8.	8.		
37	16.75	R/S	16.75	16.75		
38		2nd: C	1.168	Z		
				6303.		
				-7917.		
				-635.		
				1.168	I	
39	2.61	R/S	10602.	2.610	I	
				127.		
				10599.		
				10602.		
40	-1.25	E	-1.25	-1.25		
41	8	R/S	8	8		
42	18.	R/S	18.	18.		
43		2nd: A	1.168	X		
				7017.		
				-7832.		
				80.		
				1.168	I	
44	2.61	RS	8673.	2.610	I	
				1408.		
				8204.		
				8673.		
45	0	E	0.	0.		
46	8	R/S	8.	8.		
47	0	R/S	0.	0.		
48		2nd: B	1.168	Y		
				-3265.		
				7057.		
				-635.		
49		R/S		1.168	I	
				1.168	I	
				1416.		
				1559.		
				3233.		

Coding Form

Program Number TI-59-1 **Title** Elastic Center Part 1

Loc	Code	Key	Comments
000	98	ADV	Store next R in R22, print, using PAU.
001	42	STO	
002	22	22	
003	32	X:T	
004	03	3	
005	05	5	
006	71	SBR	
007	66	PAU	
008	91	R/S	
009	42	STO	Store next K in R23. Print, using PAU.
010	23	23	
011	32	X:T	
012	02	2	
013	06	6	
014	71	SBR	
015	66	PAU	
016	91	R/S	
017	76	LBL	Clears all memories, resets all flags. Go to 000.
018	15	E	
019	47	CMS	
020	81	RST	
021	76	LBL	Subroutine: Sums inertia into correct register. Pointer is R00.
022	16	A'	
023	95	=	
024	69	OP	
025	20	20	
026	74	SM+	
027	00	00	
028	92	RTN	
029	76	LBL	Subroutine: Prints data with alpha label.
030	66	PAU	
031	69	OP	
032	04	04	
033	32	X:T	
034	69	OP	
035	06	06	
036	92	RTN	
037	76	LBL	Subroutine: Calculates .363 R.
038	33	X²	
039	93	.	
040	03	3	
041	06	6	
042	03	3	
043	65	×	
044	43	RCL	
045	25	25	
046	95	=	
047	92	RTN	
048	76	LBL	Subroutine: Calculates values for L, L·a, L·b, L·a·b.
049	17	B'	
050	43	RCL	
051	35	35	
052	16	A'	
053	65	×	
054	43	RCL	
055	19	19	
056	16	A'	
057	43	RCL	
058	35	35	
059	65	×	

Loc	Code	Key	Comments
060	43	RCL	a and b are the distances from the origin for the plane in question.
061	20	20	
062	16	A'	
063	65	×	
064	43	RCL	
065	19	19	
066	16	A'	
067	92	RTN	
068	76	LBL	Subroutine: Performs calculations for straight inertias: X-member in X-Y plane; X-member in X-Z plane; Y-member in Y-Z plane. All torsion members in all planes.
069	18	C'	
070	17	B'	
071	43	RCL	
072	35	35	
073	65	×	
074	43	RCL	
075	20	20	
076	33	X²	
077	16	A'	
078	43	RCL	
079	32	32	
080	45	Y^X	
081	03	3	
082	55	÷	
083	01	1	
084	02	2	
085	85	+	
086	43	RCL	
087	35	35	
088	65	×	
089	43	RCL	
090	19	19	
091	33	X²	
092	16	A'	
093	92	RTN	
094	76	LBL	Subroutine: Straight intertia routine: Y-member in X-Y plane; Z-member in X-Z plane; Z-member in Y-Z plane.
095	19	D'	
096	17	B'	
097	43	RCL	
098	35	35	
099	65	×	
100	43	RCL	
101	20	20	
102	33	X²	
103	85	+	
104	43	RCL	
105	32	32	
106	45	Y^X	
107	03	3	
108	55	÷	
109	01	1	
110	02	2	
111	16	A'	
112	43	RCL	
113	35	35	
114	65	×	
115	43	RCL	
116	19	19	
117	33	X²	
118	16	A'	
119	92	RTN	

Loc	Code	Key	Comments
120	76	LBL	Subroutine: Calculates $\pi/2 \cdot K \cdot R$ (virtual length of elbow) stored in R35. Also calculates $(.149)(K)(R)^3$ and stores it in R34. All of above is for the in-plane elbow.
121	80	GRD	
122	89	π	
123	55	÷	
124	02	2	
125	65	×	
126	43	RCL	
127	27	27	
128	65	×	
129	43	RCL	
130	25	25	
131	95	=	
132	42	STO	
133	35	35	
134	93	.	
135	01	1	
136	04	4	
137	09	9	
138	65	×	
139	43	RCL	
140	27	27	
141	65	×	
142	43	RCL	
143	25	25	
144	45	Y^X	
145	03	3	
146	95	=	
147	42	STO	
148	34	34	
149	17	B'	Calls B′. For in-plane elbow the sign of $(.137)(K)(R)^3$ is determined and summed into the product inertia register for the plane in question.
150	43	RCL	
151	34	34	
152	65	×	
153	93	.	
154	09	9	
155	02	2	
156	65	×	
157	43	RCL	
158	26	26	
159	69	OP	
160	10	10	
161	95	=	
162	74	SM*	
163	00	00	
164	43	RCL	
165	35	35	
166	65	×	
167	43	RCL	Calculates Ia and Ib for inplane elbow. a and b are the distances to the origin for the plane in question.
168	20	20	
169	33	X²	
170	85	+	
171	43	RCL	
172	34	34	
173	16	A'	
174	43	RCL	
175	35	35	
176	65	×	
177	43	RCL	
178	19	19	
179	33	X²	

Loc	Code	Key	Comments
180	85	+	
181	43	RCL	
182	34	34	
183	16	A'	
184	92	RTN	
185	76	LBL	Subroutine:
186	22	INV	Calculates
187	01	1	$(\pi/2)(1.15)(R)$
188	93	.	(virtual length for
189	08	8	the outplane
190	00	0	elbows) stored in
191	06	6	R35. Also
192	65	×	calculates
193	43	RCL	$(.149)(1.15)(R)^3$ for
194	25	25	outplane elbows.
195	95	=	Stores this value in
196	42	STO	R34.
197	35	35	
198	93	.	
199	01	1	
200	07	7	
201	01	1	
202	65	×	
203	43	RCL	
204	25	25	
205	45	Y^X	
206	03	3	
207	95	=	
208	42	STO	
209	34	34	
210	92	RTN	
211	76	LBL	Subroutine:
212	12	B	Inertia calculations
213	71	SBR	for outplane
214	22	INV	elbows: X-Z elbows
215	17	B'	in X-Y plane; X-Y
216	43	RCL	elbows in X-Z
217	35	35	plane; X-Y elbows
218	65	×	in Y-Z plane.
219	43	RCL	
220	20	20	
221	33	X^2	
222	16	A'	
223	43	RCL	
224	35	35	
225	65	×	
226	43	RCL	
227	19	19	
228	33	X^2	
229	85	+	
230	43	RCL	
231	34	34	
232	16	A'	
233	92	RTN	
234	76	LBL	Subroutine:
235	13	C	Inertia calculations
236	71	SBR	for outplane
237	22	INV	elbows:
238	17	B'	Y-Z elbows in X-Y
239	43	RCL	plane; Y-Z elbows
240	35	35	in X-Z plane;
241	65	×	X-Z elbows in Y-Z
242	43	RCL	plane.
243	20	20	
244	33	X^2	
245	85	+	
246	43	RCL	
247	34	34	
248	16	A'	
249	43	RCL	
250	35	35	
251	65	×	
252	43	RCL	
253	19	19	
254	33	X^2	
255	16	A'	
256	92	RTN	
257	76	LBL	Subroutine:
258	29	CP	Rolls all
259	43	RCL	information and
260	25	25	pointers from
261	94	+/-	"this" member
262	42	STO	registers to
263	33	33	"next" member
264	94	+/-	registers.
265	65	×	
266	43	RCL	
267	31	31	
268	69	OP	
269	10	10	
270	95	=	The elbow radius
271	74	SM*	is stored in R33
272	36	36	(negative) to help
273	43	RCL	calculate straight
274	31	31	L values. The
275	42	STO	starting point for
276	29	29	the next input is
277	43	RCL	moved to the exit
278	30	30	point of the
279	42	STO	proceeding elbow.
280	28	28	
281	43	RCL	
282	36	36	
283	42	STO	
284	37	37	
285	43	RCL	
286	22	22	
287	42	STO	
288	25	25	
289	43	RCL	
290	23	23	
291	42	STO	
292	27	27	
293	92	RTN	
294	76	LBL	Subroutine:
295	14	D	Changes $\bar{a}$ and $\bar{b}$
296	43	RCL	from an X-Y plane
297	21	21	configuration to an
298	48	EXC	X-Z plane.
299	20	20	
300	42	STO	
301	21	21	
302	92	RTN	
303	76	LBL	Subroutine:
304	10	E'	Changes $\bar{a}$ and $\bar{b}$
305	43	RCL	from an X-Z plane
306	21	21	configuration to a
307	48	EXC	Y-Z plane.
308	19	19	
309	42	STO	
310	21	21	
311	92	RTN	
312	76	LBL	Subroutine:
313	32	X:T	Rolls $\bar{a}$ and $\bar{b}$ back
314	43	RCL	to the X-Y plane
315	21	21	configuration.
316	48	EXC	
317	19	19	
318	48	EXC	
319	20	20	
320	42	STO	
321	21	21	
322	92	RTN	
323	76	LBL	Subroutine:
324	30	TAN	Takes L for a
325	43	RCL	straight length and
326	33	33	stores it in R32 and
327	42	STO	R35 for Ia and Ib
328	35	35	calculations.
329	42	STO	
330	32	32	
331	92	RTN	
332	76	LBL	Subroutine:
333	52	EE	Alters memories
334	01	1	for a torsion
335	93	.	member, straight
336	03	3	inertia analysis.
337	49	PRD	
338	35	35	
339	00	0	
340	42	STO	
341	32	32	
342	92	RTN	
343	76	LBL	Input for
344	11	A	Direction codes.
345	98	ADV	Prints D with
346	42	STO	alpha label.
347	31	31	
348	32	X:T	
349	01	1	
350	06	6	
351	71	SBR	
352	66	PAU	
353	91	R/S	
354	42	STO	Input for member
355	30	30	length. Prints L
356	32	X:T	with alpha label.
357	02	2	
358	07	7	
359	71	SBR	

Loc	Code	Key	Comments
360	66	PAU	
361	01	1	Calculate pointer for member just input. Pointer is in R36.
362	08	8	
363	42	STO	
364	36	36	
365	43	RCL	
366	31	31	
367	50	I×I	
368	44	SUM	
369	36	36	
[illegible]	[illegible]	RCL	Calculate elbow identifier and store in R26.
[illegible]	[illegible]	29	
[illegible]	65	[illegible]	
[illegible]	[illegible]	RCL	
[illegible]	[illegible]	31	
[illegible]	[illegible]	=	
[illegible]	42	STO	
[illegible]	26	26	
[illegible]	[illegible]	LBL	Determines if this is the input of the first member.
[illegible]	[illegible]	LOG	
[illegible]	43	RCL	
381	28	28	
[illegible]	[illegible]	CP	
[illegible]	[illegible]	EQ	
[illegible]	[illegible]	SIN	
[illegible]	[illegible]	[illegible]	Calculates the straight length and stores it in R33.
[illegible]	[illegible]	RCL	
[illegible]	[illegible]	25	
[illegible]	[illegible]	=	
[illegible]	[illegible]	SUM	
[illegible]	[illegible]	33	
[illegible]	[illegible]	RCL	The centroid of the straight member is calculated. This distance is used for all the inertia summations (straight).
[illegible]	[illegible]	33	
393	55	÷	
394	02	2	
395	65	[illegible]	
396	43	RCL	
397	29	29	
398	69	OP	
399	10	10	
400	95	=	
401	74	SM*	
402	37	37	
403	61	GTO	
404	39	COS	
405	76	LBL	First member routine. Readies input for second member.
406	38	SIN	
407	71	SBR	
408	29	CP	
409	25	CLR	
410	91	R/S	
411	76	LBL	Determine orientation of member, X, Y, or Z.
412	39	COS	
413	00	0	
414	42	STO	
415	00	00	
416	02	2	
417	32	X:T	
418	43	RCL	
419	29	29	

Loc	Code	Key	Comments
420	50	I×I	
421	67	EQ	
422	57	ENG	
423	77	GE	
424	58	FIX	
425	71	SBR	Main controller for an X-an member straight. Inertia analysis calls all subroutines, shifts to elbow analysis.
426	30	TAN	
427	18	C'	
428	14	D	
429	18	C'	
430	71	SBR	
431	52	EE	
432	10	E'	
433	18	C'	
434	71	SBR	
435	32	X:T	
436	61	GTO	
437	70	RAD	
438	76	LBL	Main controller for a Y-member.
439	57	ENG	
440	71	SBR	
441	30	TAN	
442	19	D'	
443	71	SBR	
444	52	EE	
445	14	D	
446	18	C'	
447	71	SBR	
448	30	TAN	
449	10	E'	
450	18	C'	
451	71	SBR	
452	32	X:T	
453	61	GTO	
454	70	RAD	
455	76	LBL	Main controller for a Z-member.
456	58	FIX	
457	71	SBR	
458	30	TAN	
459	71	SBR	
460	52	EE	
461	18	C'	
462	71	SBR	
463	30	TAN	
464	14	D	
465	19	D'	
466	10	E'	
467	19	D'	
468	71	SBR	
469	32	X:T	
470	76	LBL	Begin elbow analysis. Shift "in-line" centroid from straight piece position to elbow position. This is along the axis of the member and .363 R distance from the elbow
471	70	RAD	
472	43	RCL	
473	33	33	
474	55	÷	
475	02	2	
476	85	+	
477	93	.	
478	06	6	
479	03	3	

Loc	Code	Key	Comments
480	07	7	tangent point.
481	65	×	
482	43	RCL	
483	25	25	
484	54	)	
485	65	×	
486	43	RCL	
487	29	29	
488	69	OP	
489	10	10	
490	95	=	
491	74	SM*	
492	37	37	
493	71	SBR	This calculates the centroid of the elbow perpendicular to the member axis.
494	33	X²	
495	65	×	
496	43	RCL	
497	31	31	
498	69	OP	
499	10	10	
500	95	=	
501	74	SM*	
502	36	36	
503	43	RCL	If R = 0, skip elbow routines.
504	25	25	
505	29	CP	
506	67	EQ	
507	89	π	
508	00	0	Determines orientation of elbow.
509	42	STO	
510	00	00	
511	03	3	
512	32	X:T	
513	43	RCL	
514	26	26	
515	50	I×I	
516	67	EQ	
517	98	ADV	
518	77	GE	
519	99	PRT	
520	71	SBR	Main control for an X-Y elbow. Calls all subroutines, skips to end of analysis routines.
521	80	GRD	
522	14	D	
523	12	B	
524	10	E'	
525	12	B	
526	71	SBR	
527	32	X:T	
528	61	GTO	
529	89	π	
530	76	LBL	Main control for an X-Z elbow.
531	98	ADV	
532	12	B	
533	14	D	
534	71	SBR	
535	80	GRD	
536	10	E'	
537	13	C	
538	71	SBR	
539	32	X:T	

Loc	Code	Key	Comments
540	61	GTO	
541	89	π	
542	76	LBL	Main control for a Y-Z elbow.
543	99	PRT	
544	13	C	
545	14	D	
546	13	C	
547	10	E'	
548	71	SBR	
549	80	GRD	
550	71	SBR	
551	32	X⇌T	
552	76	LBL	End of analysis routines. Readjusts coordinates to end point coordinates.
553	89	π	
554	71	SBR	
555	33	X²	
556	65	×	
557	43	RCL	
558	31	31	
559	69	OP	
560	10	10	
561	95	=	
562	94	+/-	
563	74	SM*	
564	36	36	
565	50	I×I	
566	65	×	
567	43	RCL	
568	29	29	
569	69	OP	
570	10	10	
571	95	=	
572	74	SM*	
573	37	37	
574	98	ADV	Prints point coordinates for "last" point.
575	43	RCL	
576	19	19	
577	32	X⇌T	
578	04	4	
579	04	4	
580	71	SBR	
581	66	PAU	
582	43	RCL	
583	20	20	
584	32	X⇌T	
585	04	4	
586	05	5	
587	71	SBR	
588	66	PAU	
589	43	RCL	
590	21	21	
591	32	X⇌T	
592	04	4	
593	06	6	
594	71	SBR	
595	66	PAU	
596	87	IFF	If last member, skip to CLR.
597	01	01	
598	25	CLR	
599	71	SBR	
600	29	CP	Readies input for next member.
601	25	CLR	
602	91	R/S	
603	98	ADV	Prints end-of-data flags. Sets Flag 1, skips to straight inertia analysis for last member in analysis.
604	05	5	
605	01	1	
606	69	OP	
607	00	00	
608	69	OP	
609	02	02	
610	69	OP	
611	05	05	
612	69	OP	
613	05	05	
614	86	STF	
615	01	01	
616	00	0	
617	42	STO	
618	26	26	
619	42	STO	
620	25	25	
621	61	GTO	
622	28	LOG	
623	76	LBL	Stores developed distances in new memory locations for use in Part 2.
624	25	CLR	
625	98	ADV	
626	43	RCL	
627	19	19	
628	42	STO	
629	25	25	
630	43	RCL	
631	20	20	
632	42	STO	
633	23	23	
634	43	RCL	
635	21	21	
636	42	STO	
637	24	24	
638	25	CLR	
639	91	R/S	

Coding Form

Program Number TI-59-1 **Title** Elastic Center Part 2

Loc	Code	Key	Comments
000	61	GTO	Returns to B.
001	24	CE	
002	76	LBL	Used to input data
003	13	C	in Master Library
004	36	PGM	Matrix Solver.
005	02	02	
006	91	R/S	
007	92	RTN	
008	76	LBL	Input routine:
009	11	A	Flag 3 is set
010	87	IFF	after the first bit
011	03	03	of data is input. R00
012	14	D	is used as a pointer
013	86	STF	to data registers.
014	03	03	Alpha labels are
015	32	X:T	stored in R30–R33
016	03	3	when Card 3 of
017	00	0	Part 2 is read in.
018	42	STO	
019	00	00	
020	32	X:T	
021	76	LBL	
022	14	D	
023	63	EX*	
024	00	00	
025	69	OP	
026	04	04	
027	73	RC*	
028	00	00	
029	69	OP	
030	06	06	
031	69	OP	
032	20	20	
033	91	R/S	
034	76	LBL	Resets all flags.
035	12	B	Go to 000.
036	81	RST	
037	76	LBL	Calculates elastic
038	24	CE	centers for all
039	43	RCL	three planes.
040	01	01	
041	35	1/X	
042	49	PRD	
043	02	02	
044	49	PRD	
045	03	03	
046	43	RCL	
047	07	07	
048	35	1/X	
049	49	PRD	
050	08	08	
051	49	PRD	
052	09	09	
053	43	RCL	
054	13	13	
055	35	1/X	
056	49	PRD	
057	14	14	
058	49	PRD	
059	15	15	

Loc	Code	Key	Comments
060	43	RCL	Performs inertia
061	01	01	transfers for all the
062	65	×	moments of inertia
063	43	RCL	to the elastic
064	03	03	centers of each
065	33	X^2	plane.
066	95	=	
067	94	+/-	
068	44	SUM	
069	05	05	
070	43	RCL	
071	01	01	
072	65	×	
073	43	RCL	
074	02	02	
075	33	X^2	
076	95	=	
077	94	+/-	
078	44	SUM	
079	06	06	
080	43	RCL	
081	07	07	
082	65	×	
083	43	RCL	
084	09	09	
085	33	X^2	
086	95	=	
087	94	+/-	
088	44	SUM	
089	11	11	
090	43	RCL	
091	07	07	
092	65	×	
093	43	RCL	
094	08	08	
095	33	X^2	
096	95	=	
097	94	+/-	
098	44	SUM	
099	12	12	
100	43	RCL	
101	13	13	
102	65	×	
103	43	RCL	
104	15	15	
105	33	X^2	
106	95	=	
107	94	+/-	
108	44	SUM	
109	17	17	
110	43	RCL	
111	13	13	
112	65	×	
113	43	RCL	
114	14	14	
115	33	X^2	
116	95	=	
117	94	+/-	
118	44	SUM	
119	18	18	

Loc	Code	Key	Comments
120	43	RCL	Inertia transfers
121	01	01	for the product
122	65	×	inertias to the
123	43	RCL	elastic centers.
124	02	02	
125	65	×	
126	43	RCL	
127	03	03	
128	75	-	
129	43	RCL	
130	04	04	
131	95	=	
132	42	STO	
133	04	04	
134	43	RCL	
135	07	07	
136	65	×	
137	43	RCL	
138	08	08	
139	65	×	
140	43	RCL	
141	09	09	
142	75	-	
143	43	RCL	
144	10	10	
145	95	=	
146	42	STO	
147	10	10	
148	43	RCL	
149	13	13	
150	65	×	
151	43	RCL	
152	14	14	
153	65	×	
154	43	RCL	
155	15	15	
156	75	-	
157	43	RCL	
158	16	16	
159	95	=	
160	42	STO	
161	16	16	
162	43	RCL	Sums all Ix values
163	05	05	to one register,
164	44	SUM	R11. ΣIy is in R17.
165	11	11	ΣIz is in R18.
166	43	RCL	
167	06	06	
168	44	SUM	
169	17	17	
170	43	RCL	
171	12	12	
172	44	SUM	
173	18	18	
174	43	RCL	Moves centroid
175	02	02	values to R34–R39.
176	42	STO	R01 to R22 are used
177	34	34	in the matrix
178	43	RCL	solver, so the
179	03	03	elastic center

Loc	Code	Key	Comments
180	42	STO	coordinates have to be relocated.
181	35	35	
182	43	RCL	
183	08	08	
184	42	STO	
185	36	36	
186	43	RCL	
187	09	09	
188	42	STO	
189	37	37	
190	43	RCL	
191	14	14	
192	42	STO	
193	38	38	
194	43	RCL	
195	15	15	
196	42	STO	
197	39	39	
198	43	RCL	Calculates moment of inertia for pipe and store in R26.
199	30	30	
200	45	Y^X	
201	04	4	
202	75	-	
203	53	(	
204	43	RCL	
205	30	30	
206	75	-	
207	02	2	
208	65	×	
209	43	RCL	
210	31	31	
211	54	)	
212	45	Y^X	
213	04	4	
214	54	)	
215	65	×	
216	89	π	
217	55	÷	
218	06	6	
219	04	4	
220	95	=	
221	42	STO	
222	26	26	
223	43	RCL	Calculates stress intensification factor from K factor in memory, the last K value input and stores it in R29.
224	27	27	
225	35	1/X	
226	65	×	
227	01	1	
228	93	.	
229	06	6	
230	05	5	
231	95	=	
232	45	Y^X	
233	53	(	
234	02	2	
235	55	÷	
236	03	3	
237	54	)	
238	55	÷	
239	93	.	
240	09	9	
241	95	=	
242	35	1/X	
243	42	STO	
244	29	29	
245	43	RCL	Prepares storage registers for matrix solver.
246	11	11	
247	42	STO	
248	08	08	
249	43	RCL	
250	17	17	
251	42	STO	
252	12	12	
253	43	RCL	
254	18	18	
255	48	EXC	
256	16	16	
257	42	STO	
258	13	13	
259	42	STO	
260	15	15	
261	43	RCL	
262	04	04	
263	42	STO	
264	11	11	
265	42	STO	
266	09	09	
267	43	RCL	
268	10	10	
269	42	STO	
270	14	14	
271	93	.	Changes units for thermal growth rate.
272	00	0	
273	01	1	
274	49	PRD	
275	33	33	
276	01	1	Matrix solver constants.
277	06	6	
278	42	STO	
279	01	01	
280	03	3	
281	42	STO	
282	07	07	
283	01	1	Divide all inertias by EI, convert units from ft^3 to in^3.
284	07	7	
285	02	2	
286	08	8	
287	55	÷	
288	43	RCL	
289	32	32	
290	52	EE	
291	06	6	
292	22	INV	
293	52	EE	
294	55	÷	
295	43	RCL	
296	26	26	
297	95	=	
298	49	PRD	
299	08	08	
300	49	PRD	
301	09	09	
302	49	PRD	
303	10	10	
304	49	PRD	
305	11	11	
306	49	PRD	
307	12	12	
308	49	PRD	
309	13	13	
310	49	PRD	
311	14	14	
312	49	PRD	
313	15	15	
314	49	PRD	
315	16	16	
316	43	RCL	Calculate system unrestrained expansion values.
317	33	33	
318	49	PRD	
319	23	23	
320	49	PRD	
321	24	24	
322	49	PRD	
323	25	25	
324	36	PGM	Calculate matrix determinant.
325	02	02	
326	13	C	
327	01	1	Set up program to accept anchor movements.
328	36	PGM	
329	02	02	
330	14	D	
331	25	CLR	
332	91	R/S	
333	99	PRT	Print anchor movements, add to unrestrained expansion values, and feed into the matrix solver.
334	85	+	
335	43	RCL	
336	25	25	
337	95	=	
338	13	C	
339	25	CLR	
340	98	ADV	
341	91	R/S	
342	99	PRT	
343	85	+	
344	43	RCL	
345	23	23	
346	95	=	
347	13	C	
348	25	CLR	
349	98	ADV	
350	91	R/S	
351	99	PRT	
352	85	+	
353	43	RCL	
354	24	24	
355	95	=	
356	13	C	
357	25	CLR	Solve matrix.
358	36	PGM	
359	02	02	

Loc	Code	Key	Comments
360	15	E	
361	43	RCL	Calculate pipe section modulus. Store in R24.
362	26	26	
363	55	÷	
364	43	RCL	
365	30	30	
366	65	×	
367	02	2	
368	95	=	
369	42	STO	
370	24	24	
371	01	1	Change signs to represent values at Anchor 1.
372	94	+/-	
373	49	PRD	
374	20	20	
375	49	PRD	
376	21	21	
377	49	PRD	
378	22	22	
379	58	FIX	Label and print forces.
380	00	00	
381	02	2	
382	01	1	
383	04	4	
384	04	4	
385	69	OP	
386	04	04	
387	43	RCL	
388	20	20	
389	69	OP	
390	06	06	
391	02	2	
392	01	1	
393	04	4	
394	05	5	
395	69	OP	
396	04	04	
397	43	RCL	
398	21	21	
399	69	OP	
400	06	06	
401	02	2	
402	01	1	
403	04	4	
404	06	6	
405	69	OP	
406	04	04	
407	43	RCL	
408	22	22	
409	69	OP	
410	06	06	
411	98	ADV	
412	91	R/S	
413	76	LBL	User inputs coordinates of point where moments and stresses are to be calculated.
414	15	E	
415	22	INV	
416	58	FIX	
417	98	ADV	
418	42	STO	
419	01	01	

Loc	Code	Key	Comments
420	99	PRT	
421	91	R/S	
422	42	STO	
423	02	02	
424	99	PRT	
425	91	R/S	
426	42	STO	
427	03	03	
428	99	PRT	
429	91	R/S	
430	76	LBL	Set up moment and stress routine for an X-member.
431	16	A'	
432	04	4	
433	04	4	
434	42	STO	
435	00	00	
436	07	7	
437	42	STO	
438	04	04	
439	08	8	
440	42	STO	
441	05	05	
442	09	9	
443	42	STO	
444	06	06	
445	10	E'	
446	76	LBL	Set up moment and stress routine for a Y-member.
447	17	B'	
448	04	4	
449	05	5	
450	42	STO	
451	00	00	
452	08	8	
453	42	STO	
454	04	04	
455	07	7	
456	42	STO	
457	05	05	
458	09	9	
459	42	STO	
460	06	06	
461	10	E'	
462	76	LBL	Set up moment and stress routine for a Z-member.
463	18	C'	
464	04	4	
465	06	6	
466	42	STO	
467	00	00	
468	09	9	
469	42	STO	
470	04	04	
471	07	7	
472	42	STO	
473	05	05	
474	08	8	
475	42	STO	
476	06	06	
477	76	LBL	
478	10	E'	
479	43	RCL	

Loc	Code	Key	Comments
480	00	00	Print orientation flag.
481	69	OP	
482	00	00	
483	69	OP	
484	01	01	
485	69	OP	
486	05	05	
487	98	ADV	
488	58	FIX	Calculate Mx and store in R26 and R07.
489	00	00	
490	43	RCL	
491	22	22	
492	65	×	
493	53	(	
494	43	RCL	
495	38	38	
496	75	-	
497	43	RCL	
498	02	02	
499	54	)	
500	75	-	
501	43	RCL	
502	21	21	
503	65	×	
504	53	(	
505	43	RCL	
506	39	39	
507	75	-	
508	43	RCL	
509	03	03	
510	95	=	
511	42	STO	
512	26	26	
513	99	PRT	
514	42	STO	
515	07	07	
516	43	RCL	Calculate My and store in R27 and R08.
517	20	20	
518	65	×	
519	53	(	
520	43	RCL	
521	37	37	
522	75	-	
523	43	RCL	
524	03	03	
525	54	)	
526	75	-	
527	43	RCL	
528	22	22	
529	65	×	
530	53	(	
531	43	RCL	
532	36	36	
533	75	-	
534	43	RCL	
535	01	01	
536	95	=	
537	42	STO	
538	27	27	
539	99	PRT	

Loc	Code	Key	Comments
540	42	STO	
541	08	08	
542	43	RCL	Calculate Mz and store in R28 and R09.
543	21	21	
544	65	×	
545	53	(	
546	43	RCL	
547	34	34	
548	75	-	
549	43	RCL	
550	01	01	
551	54	)	
552	75	-	
553	43	RCL	
554	20	20	
555	65	×	
556	53	(	
557	43	RCL	
558	35	35	
559	75	-	
560	43	RCL	
561	02	02	
562	95	=	
563	42	STO	
564	28	28	
565	99	PRT	
566	42	STO	
567	09	09	
568	01	1	Changes moments in R07, R08, and R09 to nominal stress values.
569	02	2	
570	55	÷	
571	43	RCL	
572	24	24	
573	95	=	
574	49	PRD	
575	07	07	
576	49	PRD	
577	08	08	
578	49	PRD	
579	09	09	
580	93	.	Adjust torsion stress.
581	05	5	
582	64	PD*	
583	04	04	
584	02	2	Label and print elbow and I value and stop.
585	04	4	
586	69	OP	
587	04	04	
588	58	FIX	
589	03	03	
590	43	RCL	
591	29	29	
592	69	OP	
593	06	06	
594	91	R/S	
595	69	OP	Print chosen I value.
596	06	06	
597	58	FIX	Multiply bending stresses by I.
598	00	00	
599	64	PD*	
600	05	05	
601	64	PD*	
602	06	06	
603	73	RC*	Calculate bending stress vector.
604	05	05	
605	32	X:T	
606	73	RC*	
607	06	06	
608	22	INV	
609	37	P/R	
610	32	X:T	
611	72	ST*	
612	05	05	
613	32	X:T	Calculate stress range.
614	73	RC*	
615	04	04	
616	65	×	
617	02	2	
618	95	=	
619	22	INV	
620	37	P/R	
621	32	X:T	
622	72	ST*	
623	06	06	
624	98	ADV	Print ST, SB, and SE values, in that order.
625	73	RC*	
626	04	04	
627	50	I×I	
628	99	PRT	
629	73	RC*	
630	05	05	
631	99	PRT	
632	73	RC*	
633	06	06	
634	99	PRT	
635	91	R/S	

TI-59-1 Input Sheet

INDEX OF TERMS

R: Elbow radius (ft)

K: Elbow flexibility factor

D: Direction code for member input
1 = X-member
2 = Y-member
3 = Z-member

L: Member length (ft)

X: Point coordinate in the X-direction (ft)

Y: Point coordinate in the Y-direction (ft)

Z: Point coordinate in the Z-direction (ft)

*: End-of-data flags

Elbow radius and K factor for elbow at Point ____________

Direction code and member length for Member ____________

Coordinates at Point ____________

Elbow radius and K factor for elbow at Point ____________

Direction code and member length for Member ____________

Coordinates at Point ____________

Elbow radius and K factor for elbow at Point ____________

Direction code and member length for Member ____________

Coordinates at Point ____________

Elbow radius and K factor for elbow at Point ____________

Direction code and member length for Member ____________

Coordinates at Point ____________

Elbow radius and K factor for elbow at Point ____________

Direction code and member length for Member ____________

Coordinates at Point ____________

Elbow radius and K factor for elbow at Point ____________

Direction code and member length for Member ____________

Coordinates at Point ____________

TI-59-1 Output Sheet 1

Pipe outside diameter (in)
Pipe wall thickness (in)
Modulus of elasticity (Mega psi)
Thermal growth rate (in/100 ft)

Inertia matrix determinant

X-anchor movement (in)
Total delta X between anchors (in)

Y-anchor movement (in)
Total delta Y between anchors (in)

Z-anchor movement (in)
Total delta Z between anchors (in)

Applied at Anchor 1 (lb)
Applied at Anchor 1 (lb)
Applied at Anchor 1 (lb)

The inertia matrix determinant is printed automatically by the Master Library Software program, used by the program (ML-02).

The anchor movements input by the user represent the total algebraic difference between the movement at Anchor 1, and the movement at Anchor 2.

Example: Anchor 1 moves 0.25″ in the *positive* X-direction.
Anchor 2 moves 0.10″ in the *negative* X-direction.

The anchor movement that the user inputs is:

$$0.25 - (-0.10) = 0.35''$$

If the movement at Anchor 2 had been 0.5″ *positive*, the user input would be:

$$0.25 - 0.50 \quad = -0.25''$$

TI-59-1 Output Sheet 2

	X-coordinate (ft) Y-coordinate (ft) Z-coordinate (ft) Orientation flag Mx (ft-lb) My (ft-lb) Mz (ft-lb) I factor (offered) I factor (used) Torsion stress Bending stress Stress range X-coordinate (ft) Y-coordinate (ft) Z-coordinate (ft) Orientation flag Mx (ft-lb) My (ft-lb) Mz (ft-lb) I factor (offered) I factor (used) Torsion stress Bending stress Stress range	

The moments at Anchor 1 (0, 0, 0) will have the *correct* sign.
The moments at Anchor 2 (last point) will have the *opposite* sign.

Program HP-41CV-1: Thermal Expansion Analysis of a Two-Anchor Piping System with Variable Pipe Size, Schedule, and Thermal Condition Capability

Introduction:

HP-41CV-1 is the mating of the Elastic Center Method of thermal pipe stress analysis with a state-of-the-art programmable calculator. The program analyzes a two-anchor piping system for thermal expansion or contraction in single or multiple planes. Bend radii at changes of direction, including square corners, can vary throughout the analysis. Also variable are the "base" data sets, which include pipe, outside diameter, wall thickness, modulus of elasticity, and thermal growth rate. Up to four "base" data sets may be used during one analysis. Anchor movements may be introduced at either anchor. The flexibility matrix may be saved on magnetic cards for reanalysis of one system under varying conditions. The analysis conforms to ASME/ANSI B31.3, 1980.

Nomenclature:

The user inputs the system geometry, pipe size, and thermal conditions to the program. The "base" data sets consist of the following items:

- OD: Pipe outside diameter (in)
- T: Pipe thickness (in)
- E: Modulus of elasticity (Mega psi)
- e: Thermal growth rate (in/100 ft)

The geometry data consist of the following items:

- Lx: Member length (ft), where x is the member number
- R: Elbow bend radius (ft)

The user will also be able to input anchor movements:

- AM1: Anchor movements at Anchor 1 consisting of three numbers, one for each of the three orthogonal directions (in)
- AM2: Same as above for Anchor 2, the final point of the analysis

Point coordinates are input by the user to find the stresses at a point of interest where:

- Cx: Point coordinate along the X-axis (ft)
- Cy: Point coordinate along the Y-axis (ft)
- Cz: Point coordinate along the Z-axis (ft)

Finally, the user will be asked to identify the stress intensification factor to be used at the stress point, and the "base" data set number:

- I: Stress intensification factor
- OD#: "Base" data set number

The user will use up to nine different keys on the calculator keyboard to execute the program. They are:

- E: Initializes the program
- A: Geometry input for an X-member
- B: Geometry input for a Y-member
- C: Geometry input for a Z-member
- D: End of geometry data
- Shift A: Stress analysis for an X-oriented member
- Shift B: Stress analysis for a Y-oriented member
- Shift C: Stress analysis for a Z-oriented member
- Shift D: Input a new "base" data set

Method:

The Elastic Center Method of piping stress analysis, sometimes called the Spielvogel Method, is described in great detail in the Grinnell Company's *Piping Design and Engineering*. Some excerpts are included here, but the reader is encouraged to examine the full text for a complete understanding of the analysis. Basically, the analysis finds the point in each of the three orthogonal planes where the moment in that plane is zero. This point is the "elastic center" of that plane, and each member in the piping system has a moment of inertia and a product inertia with respect to it. When all the moments of inertia and the product inertias for each member are summed up, the result, for a three-dimensional system, is a 3×3 flexibility matrix.

The matrix may be a simple 3×3 because the moments are all zero at the planar elastic centers. Solving with respect to a 1×3 displacement matrix results in the three orthogonal system forces. These forces, in conjunction with the developed distances, may be used to calculate the moments and stresses at any point.

When the Elastic Center Method was originally used, modern mainframe computers were unavailable or too costly. Therefore, convenient analysis forms were used to keep all the data straight and to reduce the errors that are a part of manual calculations. Still, a fairly straightforward analysis could consume several hours.

In simplifying the analysis, the forms also greatly limited its capabilities. Because it used the constant C, which is a combination of the thermal growth rate and the modulus of elasticity, the method was limited to metallic pipe at the cold modulus and one thermal condition from one anchor to another. Also, by using the pipe moment of inertia in the final equation, the analysis was limited to only one pipe size from one anchor to the other.

HP-41CV-1 allows the user to put back all the things

that had been removed. The modern programmable calculator has numerous memory registers that can separate and remember all the data that would become too cumbersome if the analysis were to be done entirely by hand. The analysis can handle up to four different combinations of pipe size and thermal conditions. The inertias are normalized to the pipe moment of inertia and present value of Young's modulus during the summation process. The thermal expansion data is accumulated for each member, based on the present value of thermal growth rate.

Another limitation of the original method has been eliminated. Originally, the entire system was first analyzed to find the various elastic centers, then all the inertias were summed with respect to those points. HP-41CV-1 uses the Luengas Summation System, named for its developer Carlos E. Luengas. This system sums all the inertias with respect to the point of origin and then transfers the inertias to the elastic centers of each plane after geometry input is complete. Thus, the calculator does not need to "know" the geometry beforehand.

Anchor movements are also possible with this program. At each anchor the user may elect to add to the analysis displacements of the anchors, thereby allowing the user to perform a seismic anchor movement analysis on a system (This is applicable to static analysis only.)

Finally, the program allows the user to save the summed inertias on magnetic cards. This step is somewhat similar to saving the decomposed stiffness matrix in a major mainframe program. It allows the user to reanalyze the same system for various combinations of anchor movement and/or various thermal conditions without having to reinput the geometry each time.

Accuracy was measured against the same geometry and thermal conditions analyzed by a major mainframe stiffness matrix method. The results follow:

	HP-41CV-1	MAINFRAME ANALYSIS
Fx	564 #	516 #
Fy	396 #	355 #
Fz	−557 #	−533 #
@ A1		
Mx	−7390 ft-lb	−7153 ft-lb
My	4035 ft-lb	3431 ft-lb
Mz	−5886 ft-lb	−5237 ft-lb
@ A2		
Mx	6942 ft-lb	7159 ft-lb
My	−1683 ft-lb	−1612 ft-lb
Mz	7106 ft-lb	6455 ft-lb
Maximum stress		
ST	601 psi	575 psi
SB	8929 psi	7237 psi
SE	9010 psi	7328 psi

Limitations:

The program is set up to handle any number of members, but only two anchors. There is no provision for intermediate supports. Fully fixed rigid anchors are assumed. Only English units may be used. The program may print a fifth "base" data set, but there is only enough memory space to handle four such sets. After printing the fifth "base" data set, the calculator will stop and display the word "NONEXISTENT." The analysis does not include dead weight or internal pressure, even in the calculation of K and I factors for the elbows.

A Word About Modeling:

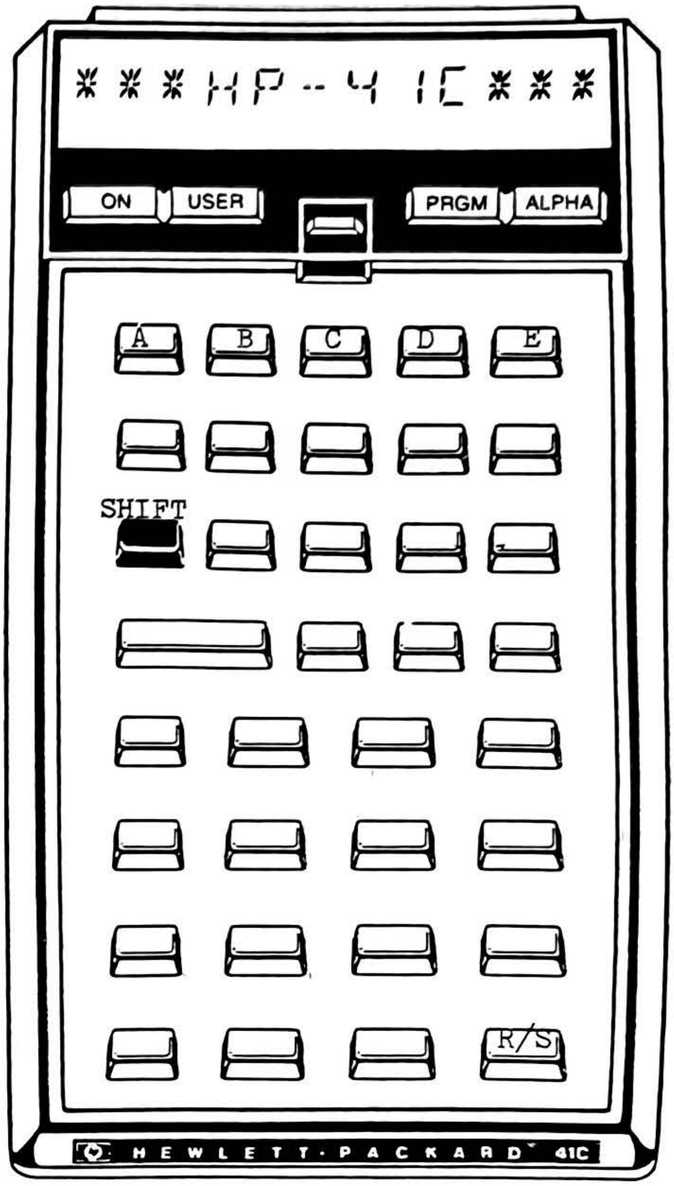
Obviously, not all piping will be routed with only two anchors. HP-41CV-1 is a tool to be used by the analyst. Complex systems must be broken down into small sections, from support to support, and combined as a whole by the analyst by manipulating the thermal conditions and anchor movements to best simulate the real situation. Many iterations and analyses may be necessary.

Special Note:

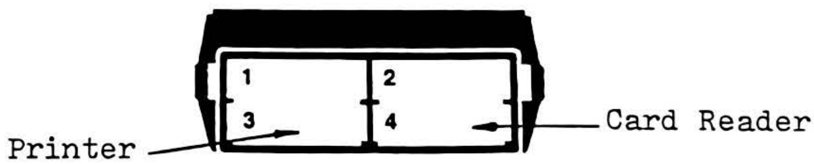
When performing the stress analysis at various points in the system, the user should be alert to the signs of the moments that are printed. At the two anchors, the moments *will* have the correct sign. But at any point between the anchors, the moments *may or may not* have the correct sign. This is because, given the limitations of program space in the HP-41CV, the program does not "know" which side of the elastic center the point is on. Analysts are cautioned to use their best judgment when determining the sign of intermediate moments. As an example, look at either of the sample problems where Point 1 is reanalyzed for stress. The moments in each case are reversed from those reported earlier in the anchor moment printout.

Keyboard Card Labeling

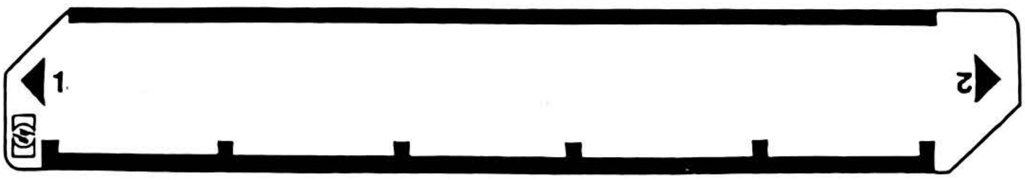
KEYBOARD



SYSTEM CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-1 **Title** Thermal Expansion Analysis

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards. Turn user mode "on" to get key assignments.			
2	Press E.			OD=
3	Enter pipe outside diameter (in).	OD	R/S	T=
4	Enter pipe thickness (in).	T	R/S	E=
5	Enter Young's Modulus (Mega psi).	E	R/S	e=
6	Enter thermal growth rate (in/100 ft).	e	R/S	L1=
7	Enter member length (ft).	L	A for X-member B for Y-member C for Z-member	R=
8	**Enter elbow radius (ft).** *Note:* For the first member, this step is mandatory. There is no default value.	R	R/S	L2=
	Repeat Steps 7 and 8 for all members of any "base" data set. If the value of R is the same as the previous value, do not reenter the value; just press the R/S key. After the last member of any "base" data set is input, the program will prompt for the "next" L. Ignore this prompt.			
9A	If there is another "base" data set to be input, press the "next data set" key. *Note:* This operation will only work three times during one complete analysis.		shift D	OD=
	Repeat Steps 3 through 8. Do *not* press the E key at this point.			
9B	After the last member of the last "base" data set has been input, the program will prompt for the "next" L. Ignore this prompt and press the end-of-data key.		D	RDY 01 OF 04
10	If the data is to be read onto magnetic cards, feed in four cards at the prompting of the calculator. If not, go to Step 11.			
11	Continue execution.		CLX : R/S	AM1=
12	Enter the anchor movements at the first point (in). *Note:* **If there are no anchor movements at the first point, do not enter zero three times. Simply press the R/S key.**	X-AM Y-AM Z-AM	ENTER ENTER R/S	X-AM Y-AM AM2=
13	Repeat Step 12 for the anchor movements at the final point. The remote printer will print the forces at Point 1 and the moments at Point 1 and the final point. At this time the user may elect to see the stresses at any point in the system. Let Cx, Cy, and Cz be the coordinates at the point of interest, expressed in feet:			
14	Enter the point coordinates (ft).	Cx Cy Cz	ENTER ENTER Shift A for X-members Shift B for Y-members Shift C for Z-members	Cx Cy

Step	Instructions	Input	Keystroke	Display
15	If the displayed value of I is appropriate, press the R/S key. If not, key in the appropriate value and press R/S.		R/S	
	OR	I	R/S	OD=1.00?
16	The program will assume that the OD is from the first "base" data set. If this is correct, press the R/S key. If the point is in another "base" data area, enter the data set number and press R/S.		R/S	
	OR	OD#	R/S	
17	Repeat Steps 14, 15, and 16 as often as necessary.			
18	If the user has recorded the data on a magnetic set of cards and wishes to analyze the system again with different anchor movements, or by manipulating the anchor movements reanalyze the system in a different thermal condition, perform the following steps:			
(a)	Press CLX.		CLX	0.00
(b)			XEQ	XEQ_ _
			ALPHA	XEQ_ _
			"RDTA"	XEQ RDTA_
			ALPHA	RDY 01 OF 04
(c)	Read in the magnetic cards recorded earlier, as prompted by the calculator.			
(d)			CLX: SF 01	
			GTO 30	
			R/S	RDY 01 OF 04
			CLX	
			R/S	AM1=
(e)	Go to Step 12.			

Registers, Flags, Assignments

Program Number HP-41CV-1 **Title** Thermal Expansion Analysis

DATA REGISTERS

00	Last R/L or 0; IND
01	OD; ST
02	T; SB
03	R (next); SE
04	E; EI
05	e; pointer
06	K; I used
07	Member #; I calculated
08	.149KR^3; X for stress
09	.137KR^3; Y for stress
10	.149K(1.15); Z for stress
11	L1; IND
12	D1; IND
13	L2; IND
14	D2; Mx
15	L straight; My
16	El #; Mz
17	Δx; Fx
18	Δy; Fy
19	Δz; Fz
20	end point & c.g. (X)
21	end point & c.g. (Y)
22	end point & c.g. (Z)
23	π/2(K)(R)
24	π/2(1.15)(R)
25	Dir code; pointer
26	L (xy)
27	L$\bar{x}$; $\bar{x}$ (Z-plane)
28	L$\bar{y}$; $\bar{y}$ (Z-plane)
29	Ixy
30	Ix (Z-plane)
31	Iy (Z-plane)
32	L (xz)
33	L$\bar{x}$; $\bar{x}$ (Y-plane)
34	L$\bar{y}$; $\bar{y}$ (Y-plane)
35	Ixz
36	Ix (Y-plane)
37	Iz (Y-plane)
38	Lyz

DATA REGISTERS

39	L$\bar{y}$; $\bar{y}$ (X-plane)
40	L$\bar{z}$; $\bar{z}$ (X-plane)
41	Iyz
42	Iy (X-plane)
43	Iz (X-plane)
44	IND
45	IND
46	R (used)
47	Z1
48	Z2
49	Z3
50	Z4

FLAGS

#	Init S/C	Set Indicates	Clear Indicates
0	C	New "base" data to be input.	
1	C	"Final" member and end of geometry input.	
2	C	Intermediate member being analyzed.	
3	C	"This" radius is the same as "last" radius.	

ASSIGNMENTS

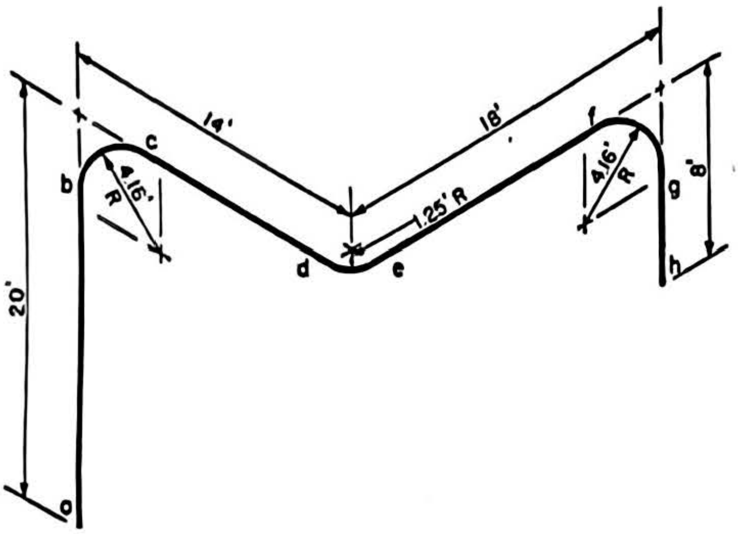
Label	Key	Function	Key
U	E (15)		
X	A (11)		
Y	B (12)		
Z	C (13)		
O	D (14)		
W	D' (-14)		
K	A' (-11)		
L	B' (-12)		
M	C' (-13)		

```
OD=10.750
T=0.365
E=27.900
e=6.170

L1.=Y=8.000
R=4.167

L2.=Z=18.000
R=1.250

PT2.=
        0.00, 8.00, 0.00

L3.=X=-7.000

PT3.=
       0.00, 8.00, 18.00

PT4.=
      -7.00, 8.00, 18.00

I=2.605
OD=10.750
T=0.365
E=27.900
e=6.170

L4.=X=-7.000
R=4.167

L5.=Y=-20.000

PT5.=
     -14.00, 8.00, 18.00

PT6.=
   -14.00, -12.00, 18.00

AM1=
         0.00 0.00 0.00
AM2=
         0.00 0.00 0.00

FX1=895.
FY1=572.
FZ1=-963.

        A1=0.00 0.00 0.00
MX=-10,969.
MY=7,056.
MZ=-7,790.

  A2=-14.00 -12.00 18.00
MX=12,232.
MY=-4,431.
MZ=10,522.
```

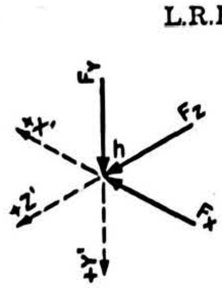
This example compares with the excerpts from "Piping Design and Engineering" by the Grinnell Company, to verify that the program performs the Elastic Center Method correctly.

```
          Y=0.00 0.00 0.00
MX=10,969.
MY=-7,056.
MZ=7,790.

I=1.00
OD=1.00
ST=1,416.
SB=5,399.
SE=6,096.

         Z=0.00 8.00 16.75
MX=-6,306.
MY=7,928.
MZ=634.

I=2.61
OD=1.00
ST=127.
SB=10,589.
SE=10,592.

       X=-1.25 8.00 18.00
MX=-7,020.
MY=7,843.
MZ=-81.

I=2.61
OD=1.00
ST=1,409.
SB=8,199.
SE=8,669.

    Y=-14.00 -12.00 18.00
MX=12,232.
MY=-4,431.
MZ=10,522.

I=1.00
OD=2.00
ST=889.
SB=6,475.
SE=6,714.

          Y=0.00 8.00 0.00
MX=3,268.
MY=-7,056.
MZ=634.

I=1.17
OD=1.00
ST=1,416.
SB=1,559.
SE=3,232.
```

MULTIPLE PLANE SYSTEM CONTAINING CIRCULAR ARCS



Bend $R = 5D_n = 4.16'$
L.R.Ell $R = 1.5D_n = 1.25'$



Given: A 10 inch piping system in accordance with the sketch shown above.

Maximum Operating Pressure P	350 psi
Maximum Operating Temperature	750° F
Piping Specification	A.S.T.M. A-106 Grade A

Data:

t = 0.365 inches = schedule 40	page 2 and 14
d = 10.02 inches	page 14
I_P = 160.8 inches^4	
S_m = 29.9 inches^3	
A_I = 78.9 inches^2	
A_M = 11.91 inches^2	
k_{bend} = 2.44	
i_{bend} = 1.17	
k_{elbow} = 8.15	
i_{elbow} = 2.61	
$c_{at\ 750°}$ = 996	page 11
Allow. S_A = 17,075 psi	page 3

Find: Reaction forces F_x, F_y and F_z at point h (at point a reaction forces equal and opposite).

Reaction moments M_{xy}, M_{xz} and M_{yz} at points a and h. Amount and location of Maximum Combined Stress, s.

Solution: Project the piping system into the three planes, determine the location of the centroid and calculate the line inertias in the same manner as outlined on page 56, except that the flexibility factor, k, must be included for all curved segments in the plane of projection.

$$\text{Total } I_x = 1993 + 3283 = 5276 \text{ ft}^3$$
$$\text{Total } I_y = 2802 + 3841 = 6643 \text{ ft}^3$$
$$\text{Total } I_z = 3091 + 1978 = 5069 \text{ ft}^3$$

$$I_{xy} = 1334 \text{ ft}^3$$
$$I_{xz} = 1774 \text{ ft}^3$$
$$I_{yz} = 706 \text{ ft}^3$$

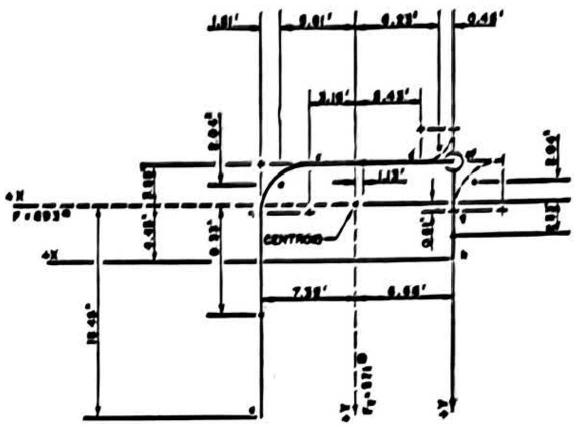
$$L_x c I_P = 14 \times 996 \times 160.8 = 2{,}242{,}195 \text{ lb ft}^3$$
$$L_y c I_P = 12 \times 996 \times 160.8 = 1{,}921{,}882 \text{ lb ft}^3$$
$$L_z c I_P = 18 \times 990 \times 160.8 = 2{,}882{,}822 \text{ lb ft}^3$$

(1) $F_x\,5278 - F_y\,1400 - F_z\,1779 = 2{,}242{,}195$

(2) $-F_x\,1400 + F_y\,6643 - F_z\,706 = 1{,}921{,}882$

(3) $-F_x\,1779 - F_y\,706 + F_z\,5069 = 2{,}882{,}822$

PROJECTION IN XY PLANE



To find c.g. of each segment see page 44.

Lengths:

$ab = 15.84'$
$cd = 8.59'$
$ef = 12.59'$
$gh = 3.84'$

Radii:

$bc - R = 4.16'$
$de - R = 1.25'$
$fg - R = 4.16'$

Centroid (calculated with origin at point h)

	Eq. No.	Length L, Ft	x'	Lx'	y'	Ly'
ab	I	15.84	+14	+222.0	+4.08	+ 64.6
bc	III	$1.57 \times 2.44 \times 4.16 = 15.94$	+12.49	+199.1	−6.49	−103.5
cd	I	8.59	+ 5.55	+ 47.7	−8	− 68.7
de	V	$1.81 \times 1.25 = 2.26$	+ 0.45	+ 1.0	−8	− 18.1
ef	II	$1.3 \times 12.59 = 16.35$	0	0	−8	−130.8
fg	V	$1.81 \times 4.16 = 7.54$	0	0	−6.49	− 48.9
gh	I	3.84	0	0	−1.92	− 7.4
		$\Sigma L = 70.36$		$\Sigma Lx' = 469.8$		$\Sigma Ly' = -312.8$

$$\bar{x} = \frac{+469.8}{70.36} = +6.68 \text{ ft} \qquad \bar{y} = \frac{-312.8}{70.36} = -4.45 \text{ ft}$$

I_{xy}

ab	VI	$15.84 \times 7.32 \times 8.53$	= + 989
bc	X B	$+2.44(0.137 \times 4.16^3) + 1.57 \times 2.44 \times 4.16 \times 5.81(-2.04)$	= − 165
cd	VI	$8.59(-1.13)(-3.55)$	= + 34.4
de	XI	$1.81 \times 1.25(-6.23)(-3.55)$	= + 50.0
ef	VIII	$1.3 \times 12.59(-6.68)(-3.55)$	= + 388.0
fg	XI	$1.81 \times 4.16(-6.68)(-2.04)$	= + 102.5
gh	VI	$3.84(-6.68)(2.53)$	= − 64.9
			I_{xy} = +1334

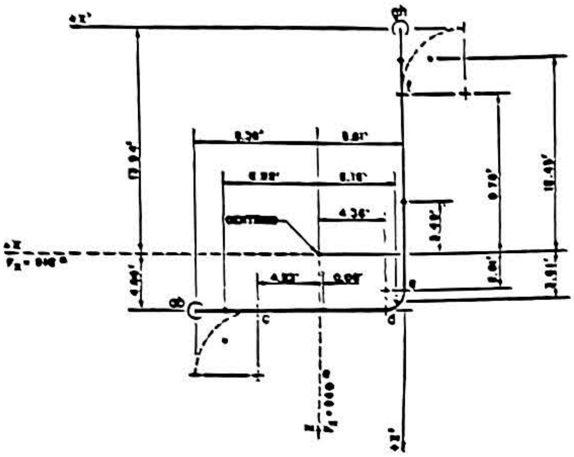
I_x

ab	XIV B	$\frac{(15.84)^3}{12} + 15.84(8.53)^2$	= 1484
bc	XVII A	$2.44(0.149 \times 4.16^3) + 1.57 \times 2.44 \times 4.16(2.04)^2$	= 92.5
cd	XIV A	$8.59(3.55)^2$	= 108.3
de	XVIII A	$1.81 \times 1.25(3.55)^2$	= 28.5
ef	XVI	$1.3 \times 12.59(3.55)^2$	= 206.3
fg	XVIII B	$1.15(0.149 \times 4.16^3) + 1.81 \times 4.16(2.04)^2$	= 43.7
gh	XIV B	$\frac{(3.84)^3}{12} + 3.84(2.53)^2$	= 29.3
			I_x = 1993

I_y

ab	XIV A	$15.84(7.32)^2$	= 849
bc	XVII B	$2.44(0.149 \times 4.16^3) + 1.57 \times 2.44 \times 4.16(5.81)^2$	= 564
cd	XIV B	$\frac{(8.59)^3}{12} + 8.59(1.13)^2$	= 63.8
de	XVIII B	$1.15(0.140 \times 1.25^3) + 1.81 \times 1.25(6.23)^2$	= 88.1
ef	XVI	$1.3 \times 12.59(6.68)^2$	= 730
fg	XVIII A	$1.81 \times 4.16(6.68)^2$	= 336
gh	XIV A	$3.84(6.68)^2$	= 171
			I_y = 2802

PROJECTION IN XZ PLANE



To find c.g. of each segment see page 44.

Lengths:

$ab = 15.84'$
$cd = 8.59'$
$ef = 12.59'$
$gh = 3.84'$

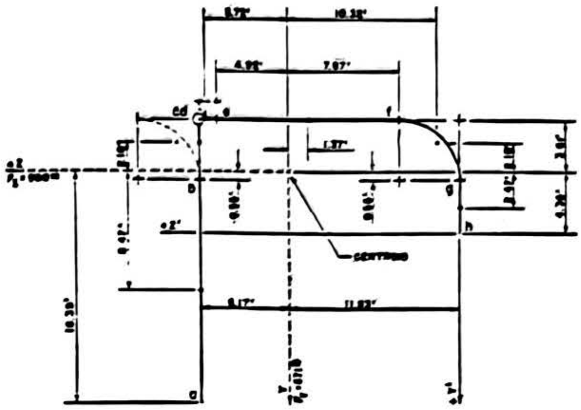
Radii:

$bc - R = 4.16'$
$de - R = 1.25'$
$fg - R = 4.16'$

Centroid (calculated with origin at point *h*)

	Eq. No.	Length L, Ft	x'	Lx'	z'	Lz'
ab	II	$1.3 \times 15.84 = 20.60$	+14	+288	+18	+ 371
bc	V	$1.81 \times 4.16 = 7.54$	+12.49	+ 94.1	+18	+ 135.8
cd	I	8.59	+ 5.55	+ 47.7	+18	+ 154.8
de	III	$1.57 \times 8.15 \times 1.25 = 16.00$	+ 0.45	+ 47.2	+17.55	+ 280.8
ef	I	12.59	0	0	+10.46	+ 131.8
fg	V	$1.81 \times 4.16 = 7.54$	0	0	+ 1.51	+ 11.4
gh	II	$1.3 \times 3.84 = 4.99$	0	0	0	0
		$\Sigma L = 77.85$		$\Sigma Lx' = +437.0$		$\Sigma Lz' = +1085.6$
		$\bar{x} = \frac{437.0}{77.85} = +5.61$ ft		$\bar{z} = \frac{1085.6}{77.85} = +13.94$ ft		
		I_{xz}				
ab	VIII	$1.3 \times 15.84 \times 8.39 \times 4.06$				+ 701
bc	XI	$1.81 \times 4.16 \times 6.88 \times 4.06$				+ 210
cd	VI	$8.59(-.06)4.06$				− 2.1
de	X *B*	$8.15(0.137 \times 1.25^2) + 1.57 \times 8.15 \times 1.25(-5.16)(3.61)$				− 296
ef	VI	$12.59(-5.61)(-3.49)$				+ 246
fg	XI	$1.81 \times 4.16(-5.61)(-12.43)$				+ 525
gh	VIII	$1.3 \times 3.84(-5.61)(-13.94)$				+ 390
						$I_{xz} = +1774$
		I_x				
ab	XVI	$1.3 \times 15.84(4.06)^2$				340
bc	XVIII *A*	$1.81 \times 4.16(4.06)^2$				124
cd	XIV *A*	$8.59(4.06)^2$				142
de	XVII *A*	$8.15(0.149 \times 1.25^2) + 1.57 \times 8.15 \times 1.25(3.61)^2$				211
ef	XIV *B*	$\frac{(12.59)^2}{12} + 12.59(3.49)^2$				320
fg	XVIII *B*	$1.15(0.149 \times 4.16^2) + 1.81 \times 4.16(12.43)^2$				1176
gh	XVI	$1.3 \times 3.84(13.94)^2$				970
						$I_x = 3283$
		I_z				
ab	XVI	$1.3 \times 15.84(8.39)^2$				1450
bc	XVIII *B*	$1.15(0.149 \times 4.16^2) + 1.81 \times 4.16(6.88)^2$				369
cd	XIV *B*	$\frac{(8.59)^2}{12} + 8.59(.06)^2$				53
de	XVII *B*	$8.15(0.149 \times 1.25^2) + 1.57 \times 8.15 \times 1.25(5.16)^2$				429
ef	XIV *A*	$12.59(5.61)^2$				396
fg	XVIII *A*	$1.81 \times 4.16(5.61)^2$				237
gh	XVI	$1.3 \times 3.84(5.61)^2$				157
						$I_z = 3091$

PROJECTION IN *YZ* PLANE



To find c.g. of each segment see page 44.

Lengths:

ab = 15.84′
cd = 8.59′
ef = 12.59′
gh = 3.84′

Radii:

bc − *R* = 4.16′
de − *R* = 1.25′
fg − *R* = 4.16′

Centroid (calculated with origin at point *h*)

	Eq. No.	Length *L*, Ft	*y′*	*Ly′*	*z′*	*Lz′*
ab	I	15.84	+4.08	+ 64.6	+18	285.5
bc	V	1.81 × 4.16 = 7.54	−6.49	− 48.9	+18	135.8
cd	II	1.3 × 8.59 = 11.18	−8	− 89.5	+18	201.5
de	V	1.81 × 1.25 = 2.26	−8	− 18.1	+17.55	39.7
ef	I	12.59	−8	−100.8	+10.46	131.7
fg	III	1.57 × 2.44 × 4.16 = 15.94	−6.49	−103.5	+ 1.51	24.1
gh	I	3.84	−1.92	− 7.4	0	0
		$\Sigma L = 69.19$		$\Sigma Ly' = -303.6$		$\Sigma Lz' = 818.3$
		$\bar{y} = \frac{-303.6}{69.19} = -4.39$ ft		$\bar{z} = \frac{818.3}{69.19} = +11.83$ ft		

I_{yz}

	Eq. No.		
ab	VI	15.84 × 8.47 × 6.17	= + 827.7
bc	XI	1.81 × 4.16(−2.10) × 6.17	= − 97.7
cd	VIII	1.3 × 8.59(−3.61) × 6.17	= − 249
de	XI	1.81 × 1.25(−3.61) × 5.72	= − 46.7
ef	VI	12.59(−3.61)(−1.37)	= + 62.3
fg	X *A*	$-2.44(0.137 \times 4.16^3) + 1.57 \times 2.44 \times 4.16(-2.10)(-10.32)$	= + 321.4
gh	VI	3.84 × 2.47(−11.83)	= − 112
			I_{yz} = + 706

I_y

	Eq. No.		
ab	XIV *A*	$15.84(6.17)^2$	= 603
bc	XVIII *A*	$1.81 \times 4.16(6.17)^2$	= 287
cd	XVI	$1.3 \times 8.59(6.17)^2$	= 426
de	XVIII *B*	$1.15(0.149 \times 1.25^3) + 1.81 \times 1.25(5.72)^2$	= 74
ef	XIV *B*	$\frac{(12.59)^2}{12} + 12.59(1.37)^2$	= 190
fg	XVII *B*	$2.44(0.149 \times 4.16^3) + 1.57 \times 2.44 \times 4.16(10.32)^2$	= 1724
gh	XIV *A*	$3.84(11.83)^2$	= 537
			I_y = 3841

I_z

	Eq. No.		
ab	XIV *B*	$\frac{(15.84)^2}{12} + 15.84(8.47)^2$	= 1468
bc	XVIII *B*	$1.15(0.149 \times 4.16^3) + 1.81 \times 4.16(2.10)^2$	= 46
cd	XVI	$1.3 \times 8.59(3.61)^2$	= 146
de	XVIII *A*	$1.81 \times 1.25(3.61)^2$	= 29.5
ef	XIV *A*	$12.59(3.61)^2$	= 164.0
fg	XVII *A*	$2.44(0.149 \times 4.16^3) + 1.57 \times 2.44 \times 4.16(2.10)^2$	= 96.5
gh	XIV *B*	$\frac{(3.84)^2}{12} + 3.84(2.47)^2$	= 23
			I_z = 1978

SOLUTION OF EQUATIONS

Line	F_x	F_y	F_z	Constant		Line
(1) (4)	+5276 −1	−1334 +0.253	−1774 +0.336	−2,242,195 +425		(1) (4)
(2) (5)	−1334 +1334	+6643 −337	−706 −449	−1,921,882 −567,275		(2) (5)
(6) (7)	0	+6306 −1	−1155 +0.183	−2,489,157 +395		(6) (7)
(3) (8) (9)	−1774 +1774	−706 −449 +1155	+5069 −596 −211	−2,882,322 −753,378 −455,516		(3) (8) (9)
(10) (11)	0	0	+4262 −1	−4,091,716 +960		(10) (11)
(11A) (11B)			$-F_z$ F_z =	+960 = +960 =	0 +960	(11A) (11B)
(7A) (7B)		$-F_y$ F_y =	+0.183 × 960 +176	+395 = +395 =	0 +571	(7A) (7B)
(4A) (4B)	$-F_x$ F_x =	+0.253 × 571 +144	+0.336 × 960 +323	+425 = +425 =	0 +893	(4A) (4B)

F_x = 893 lb F_y = 571 lb F_z = 960 lb

MOMENTS IN FOOT POUNDS

	XY Plane	*XZ* Plane	*YZ* Plane
a	+893 × 16.45 − 571 × 7.32 = +10,510	+893 × 4.06 − 960 × 8.39 = −4429	−571 × 6.17 + 960 × 16.39 = +12,211
	$M = \sqrt{(10{,}510)^2 + (12{,}211)^2} = 16{,}111$ $T_s = 4429$		
b	+893 × 0.61 − 571 × 7.32 = −3635	Same as *a* = −4429	−571 × 6.17 + 960 × 0.55 = −2995
	$M = \sqrt{(3635)^2 + (2995)^2} = 4710$ $T_s = 4429$		
c	−893 × 3.55 − 571 × 3.16 = −4974	+893 × 4.06 − 960 × 4.23 = −435	−571 × 6.17 − 960 × 3.61 = −6989
	$M = \sqrt{(4974)^2 + (435)^2} = 4993$ $T_s = 6989$		
d	−893 × 3.55 + 571 × 5.43 = −70	+893 × 4.06 + 960 × 4.36 = +7811	Same as *c* = −6989
	$M = \sqrt{(7811)^2 + (70)^2} = 7811$ $T_s = 6989$		
e	−893 × 3.55 + 571 × 6.68 = +644	+893 × 2.81 + 960 × 5.61 = +7895	−571 × 4.92 − 960 × 3.61 = −6275
	$M = \sqrt{(7895)^2 + (6275)^2} = 10{,}085$ $T_s = 644$		
f	Same as *e* = +644	−893 × 9.78 + 960 × 5.61 = −3348	+571 × 7.67 − 960 × 3.61 = +914
	$M = \sqrt{(3348)^2 + (914)^2} = 3471$ $T_s = 644$		
g	+893 × 0.61 + 571 × 6.68 = +4359	−893 × 13.94 + 960 × 5.61 = −7063	+571 × 11.83 + 960 × 0.55 = +7283
	$M = \sqrt{(4359)^2 + (7283)^2} = 8488$ $T_s = 7063$		
h	+893 × 4.45 + 571 × 6.68 = +7788	Same as *g* = −7063	+571 × 11.83 + 960 × 4.39 = +10,969
	$M = \sqrt{(7788)^2 + (10{,}969)^2} = 13{,}453$ $T_s = 7063$		

I. From inspection the maximum bending moment, M, is 16,111 ft lb occurring at point a which is straight pipe. The accompanying torque T is 4429 ft lb.

II. The maximum torque T is 6989 ft lb in line cd and the larger accompanying bending moment, M, is 7811 ft lb at point d which is curved pipe with an i factor of 2.61.

III. The maximum bending moment, M, in curved pipe with an i factor of 2.61 is 10,085 ft lb at point e with an accompanying torque T of 644 ft lb.

IV. The bending moments in curved pipe with an i factor of 1.17 are relatively small (points b, c, f, and g) and therefore need not be considered.

The maximum expansion stress is determined in the manner outlined on page 3 as follows:

Case I (at point a)

M = 16,111 ft lb
= 16,111 × 12 = 193,332 inch pounds

T = 4429 ft lb
= 4429 × 12 = 53,148 inch pounds

$$s_B = \frac{M}{S_m} = \frac{193{,}332}{29.9} = 6466 \text{ psi}$$

$$s_T = \frac{T}{2S_m} = \frac{53{,}148}{2 \times 29.9} = 889 \text{ psi}$$

$$s_E = \sqrt{(s_B)^2 + 4(s_T)^2} = \sqrt{(6466)^2 + 4(889)^2} = 6706 \text{ psi}$$

Case II (at point d)

M = 7811 ft lb
= 7811 × 12 = 93,732 inch pounds

T = 6989 ft lb
= 6989 × 12 = 83,868 inch pounds

$$s_B = \frac{M}{S_m} i = \frac{93{,}732}{29.9} \times 2.61 = 8182 \text{ psi}$$

$$s_T = \frac{T}{2S_m} = \frac{83{,}868}{2 \times 29.9} = 1402 \text{ psi}$$

$$s_E = \sqrt{(s_B)^2 + 4(s_T)^2} = \sqrt{(8182)^2 + 4(1402)^2} = 8649 \text{ psi}$$

Case III (at point e)

M = 10,085 ft lb
= 10,085 × 12 = 121,020 inch pounds

T = 644 ft lb
= 644 × 12 = 7728 inch pounds

$$s_B = \frac{M}{S_m} i = \frac{121{,}020}{29.9} \times 2.61 = 10{,}564 \text{ psi}$$

$$s_T = \frac{T}{2S_m} = \frac{7728}{2 \times 29.9} = 129 \text{ psi}$$

$$s_E = \sqrt{(s_B)^2 + 4(s_T)^2} = \sqrt{(10{,}564)^2 + 4(129)^2} = 10{,}567 \text{ psi}$$

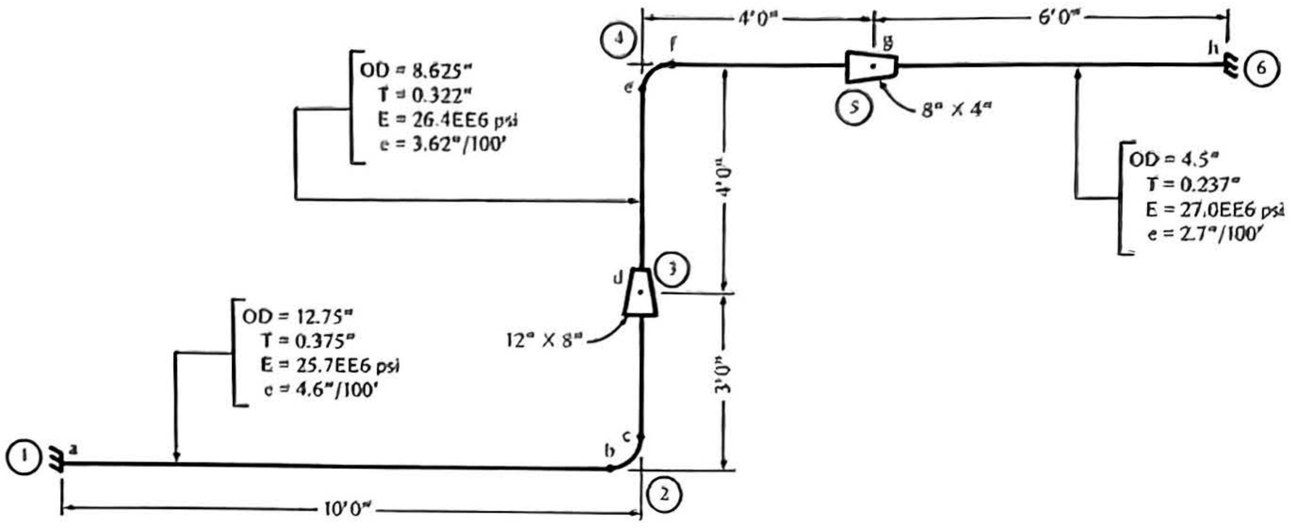
The maximum expansion stress s_E is 10,567 psi, occurring at point c, and is less than the allowable stress range S_A of 17,675 psi.

```
OD=12.750
T=0.375
E=25.700
e=4.600

L1.=X=10.000
R=1.500

L2.=Y=3.000

PT2.=
      10.00, 0.00, 0.00


PT3.=
      10.00, 3.00, 0.00

I=2.862
OD=8.625
T=0.322
E=26.400
e=3.620

L3.=Y=4.000
R=1.000

L4.=X=4.000

PT4.=
      10.00, 7.00, 0.00


PT5.=
      14.00, 7.00, 0.00

I=2.439
OD=4.500
T=0.237
E=27.000
e=2.700

L5.=X=6.000
R=0.000


PT6.=
      20.00, 7.00, 0.00

AM1=
      0.00 0.00 0.00
AM2=
      0.00 0.00 0.00

FX1=-5,309.
FY1=-2,158.
FZ1=0.
```

This example compares with the sample problem that follows. It shows how the program expands on the original use of the elastic center.

```
      A1=0.00 0.00 0.00
MX=0.
MY=0.
MZ=1,131.


      A2=20.00 7.00 0.00
MX=0.
MY=0.
MZ=-6,980.


      X=0.00 0.00 0.00
MX=0.
MY=0.
MZ=-1,131.

I=1.00
OD=1.00
ST=0.
SB=310.
SE=310.

      X=10.00 0.00 0.00
MX=0.
MY=0.
MZ=-22,635.

I=2.86
OD=1.00
ST=0.
SB=17,742.
SE=17,742.

      Y=10.00 7.00 0.00
MX=0.
MY=0.
MZ=14,524.

I=2.44
OD=2.00
ST=0.
SB=25,287.
SE=25,287.

      X=20.00 7.00 0.00
MX=0.
MY=0.
MZ=-6,980.

I=1.00
OD=3.00
ST=0.
SB=26,057.
SE=26,057.
```

Figure 1.1 Sample Problem



DATA

12″ std wt. @ 600 F
$E = 25.7 \times 10EE6$; $e = 4.6$ in/100 ft
$I = ((12.75)^4 - (12)^4)(\pi)/64 = 279.335$ in^4
$EI = 7178910155$ #-in^2

8″ sch 40 @ 500 F
$E = 26.4 \times 10EE6$; $e = 3.62$ in/100 ft
$I = 72.489$ in^4
$EI = 1913715952$ #-in^2

4″ sch 40 @ 400 F
$E = 27.0 \times 10EE6$; $e = 2.7$ in/100 ft
$I = 7.233$ in^4
$EI = 195280206.7$ #-in^2

K factor for 12-in IPS elbow with 18-in radius
$= 1.65/((18)(.375)/((12.75 - 0.375)/2)^2) = 9.359$

K factor for 8-in IPS elbow with 12-in radius
$= 1.65/((12)(0.322)/((8.625 - 0.322)/2)^2) = 7.360$

Virtual length for 12-in elbow $= (\frac{\pi}{2})(9.359)(1.5) =$ 22.052 ft

Virtual length for 8-in elbow $= (\frac{\pi}{2})(7.360)(1.0) =$ 11.561 ft

	a-b	b-c	c-d	d-e	e-f	f-g	g-h	TOTALS
LENGTH	8.5000	22.052	1.500	3.000	11.561	3.000	6.000	44.052
L/EI	1.18402 EE-9	3.07178 EE-9	2.08945 EE-10	1.56763 EE-9	6.04113 EE-9	1.56763 EE-9	3.07251 EE-8	4.43662 EE-8
$\bar{x}$	4.250	9.456	10.000	10.000	10.363	12.500	17.000	
$\bar{y}$	0.000	0.545	2.250	4.500	6.637	7.000	7.000	
$L\bar{x}$	36.125	208.524	15.000	30.000	119.807	37.500	102.000	548.956
$L\bar{x}$/EI	5.03210 EE-9	2.90467 EE-8	2.08945 EE-9	1.56763 EE-8	6.26044 EE-8	1.95954 EE-8	5.22326 EE-7	6.56370 EE-7
$L\bar{y}$	0.000	12.018	3.375	13.500	76.730	21.000	42.000	168.623
$L\bar{y}$/EI	0.000	1.67407 EE-9	4.70127 EE-10	7.05434 EE-9	4.00948 EE-8	1.09734 EE-8	2.15076 EE-7	2.75343 EE-7

Table 1.1
Data for Sample Problem

Ix

a-b $(8.5)(0.000)^2 = 0.000$

b-c $(.149)(9.359)(1.5)^3 + 22.052(.545)^2 = 11.256$
11.256/7178910155. = $\underline{1.56798 \text{ EE-9}}$

c-d $\dfrac{(1.5)^3}{12} + (1.5)(2.25)^2 = 7.875$
7.875/7178910155. = $\underline{1.09696 \text{ EE-9}}$

d-e $\dfrac{(3)^3}{12} + (3)(4.500)^2 = 63.000$
63.000/1913715952. = $\underline{3.29202 \text{ EE-8}}$

e-f $(.149)(7.360)(1)^3 + (11.561)(6.637)^2 = 510.356$
510.356/1913715952. = $\underline{2.66683 \text{ EE-7}}$

f-g $(3)(7)^2 = 147.000$
147.000/1913715952. = $\underline{7.68139 \text{ EE-8}}$

g-h $(6)(7)^2 = 294.000$
294.000/195280206.7 = $\underline{1.50553 \text{ EE-6}}$

TOTAL Ix = $\underline{1.88461 \text{ EE-6}}$

Iy

a-b $\dfrac{(8.5)^3}{12} + (8.5)(4.250)^2 = 204.708$
204.708/7178910155. = $\underline{2.85152 \text{ EE-8}}$

b-c $(.149)(9.359)(1.5)^3 + 22.052(9.456)^2 = 1976.507$
1976.507/7178910155. = $\underline{2.75321 \text{ EE-7}}$

c-d $(1.5)(10.000)^2 = 150.000$
150.000/7178910155. = $\underline{2.08945 \text{ EE-8}}$

d-e $(3)(10.000)^2 = 300.000$
300.000/1913715952. = $\underline{1.56763 \text{ EE-7}}$

e-f $(.149)(7.360)(1)^3 + (11.561)(10.363)^2 = 1242.653$
1242.653/1913715952. = $\underline{6.49340 \text{ EE-7}}$

f-g $\dfrac{(3)^3}{12} + (3)(12.500)^2 = 471.000$
471.000/1913715952. = $\underline{2.46118 \text{ EE-7}}$

g-h $\dfrac{(6)^3}{12} + (6)(17.000)^2 = 1752.000$
1752.000/195280206.7 = $\underline{8.97172 \text{ EE-6}}$

TOTAL Iy = $\underline{1.03487 \text{ EE-5}}$

Ixy

a-b (8.5)(4.25)(0) = 0

b-c $(.137)(9.359)(1.5)^3 + (22.052)(9.456)(.545) = 117.973$
117.973/7178910155. = <u>1.64332 EE-8</u>

c-d (1.5)(10)(2.25) = 33.750
33.750/7178910155. = <u>4.70127 EE-9</u>

d-e (3)(10)(4.5) = 135.000
135.000/1913715952. = <u>7.05434 EE-8</u>

e-f $(.137)(7.360)(1)^3 + (11.561)(10.363)(6.637) = 796.165$
796.165/1913715952. = <u>4.16031EE-7</u>

f-g (3)(12.5)(7) = 262.500
262.500/1913715952. = <u>1.37168 EE-7</u>

g-h (6)(17)(7) = 714.000
714.000/195280206.7 = <u>3.65628 EE-6</u>

TOTAL Ixy = <u>4.30116 EE-6</u>

COMPUTATION OF ELASTIC CENTER AND INERTIA TRANSFERS

$\bar{x} = (6.56370\text{ EE-7})/(4.43662\text{ EE-8}) = 14.79437'$
$\bar{y} = (2.75343\text{ EE-7})/(4.43662\text{ EE-8}) = 6.20614'$

$Ix = (1.88461\text{ EE-6}) - (6.20614)^2(4.43662\text{ EE-8}) = 1.75794\text{ EE-7}$

$Iy = (1.03487\text{ EE-5}) - (14.79437)^2(4.43662\text{ EE-8}) = 6.38120\text{ EE-7}$

$Ixy = (14.79437)(6.20614)(4.43662\text{ EE-8}) - (4.30116\text{ EE-6})$
$= -2.27636\text{ EE-7}$ (use absolute value)

SYSTEM DEFLECTIONS

$\Delta = (10)(.046) + (4)(.0362) + (6)(.027) = 0.7668''$
$\Delta = (3)(.046) + (4)(.0362) = 0.2828''$

SYSTEM FORCES

$$Fx = -\frac{(6.38120\text{ EE-7})(.7668) + (2.27636\text{ EE-7})(.2828)}{(1.75794\text{ EE-7})(6.38120\text{ EE-7}) - (2.27636\text{ EE-7})^2}\Big/ 1728 = -5308.525\#$$

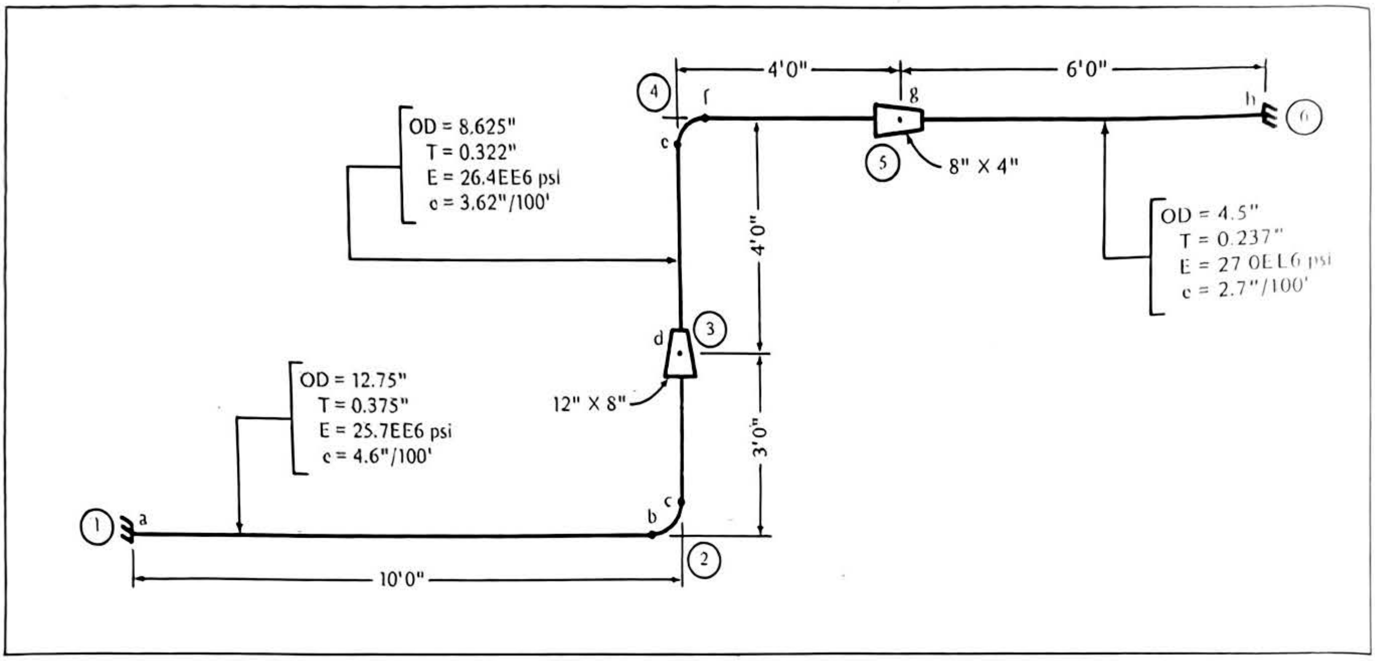
$$Fx = -\frac{(1.75794\text{ EE-7})(.2828) + (2.27636\text{ EE-7})(.7668)}{(1.75794\text{ EE-7})(6.38120\text{ EE-7}) - (2.27636\text{ EE-7})^2}\Big/ 1728 = -2150.174\#$$

MOMENTS AT ANCHORS

Mz @ a = (−2150)(14.79437) − (−5309)(6.20614) = 1141 ft-lb
Mz @ h = (2150)(14.79437 − 20) − (5309)(6.20614 − 7) = −6978 ft-lb

Sample Problem

Program: HP 41CV-1 Title Thermal Expansion Analysis



Input	Function	Display	Comments
	E	OD=	Prompts for OD of first "base" data set.
12.75	R/S	T=	Stores OD in R01, prompts for T.
.375	R/S	E=	Stores T in R02, prompts for E.
25.7	R/S	e=	Multiplies E by 10 EE6 and stores the result in R04; prompts for e.
4.6	R/S	L1=	Divides e by 100 and stores the result in R05, calculates the moment of inertia for the 12" pipe, and gets EI for the 12" pipe, in R04. Stores the section modulus for the 12" pipe in R47. Prompts for L1.
10	A	R=	Stores L1 in R13, sets the pointers for an X-member, accumulates the Δx into R17. Prompts for R.
1.5	R/S	L2=	Stores "next" R in R03. Calculates the direction code and stores it in R14. Calculates all the elbow data and stores them in the appropriate registers. Rolls all the data from "next" member registers to "this" member registers. Prompts for L2.
3	B	R=	Stores L2. Prompts for R.
	R/S	L3=	Performs all the inertia summations on L1 and the following 12" elbow. All summations are keyed to the correct registers and subroutines by the direction code and the elbow number (in R16). The c.g. of each member is calculated as the summations take place. When the summations are complete, the data in "next" member registers are rolled to "this" member registers, and "this" radius is rolled to "last" radius register. Prompts for L3.

Input	Function	Display	Comments
	shift D	OD=	Sets Flag 0. This tells the program that the L2 (in this case) is the last member in the first "base" data set, and that a second "base" data set will be input. The summations are performed on L2, but the elbow summations are skipped because there is no following elbow. The I factor for the 12" elbow is printed for use in the stress analysis section. Prompts for the new OD.
8.625	R/S	T=	
.322	R/S	E=	Same as for the first "base" data set.
26.4	R/S	e=	The Z for the 8" pipe is stored in R48.
3.62	R/S	L3=	Prompts for L3.
4	B	R=	
1	R/S	L4=	Same process as above for L1. Prompts for L4.
4	A	R=	
	R/S	L5=	Same process for the 8" pipe and the following elbow. Prompts for L5.
	shift D	OD=	Readies the program for the input of the last "base" data set. The program functions in this case the same as above.
4.5	R/S	T=	
.237	R/S	E=	Z for the 4" pipe is stored in R49.
27	R/S	e=	
2.7	R/S	L5=	
6	A	R=	
0	R/S	L6 =	
	D	RDY 01 OF 04 AM1=	Sets Flag 3. This tells the program that the final member of the analysis was L5. The summations are done for L5 but not the elbow routines. The end point coordinates are found in R20, R21, and R22. The program prompts for the user to record all the data in memory onto magnetic cards. After the cards are recorded, the program automatically goes on. The inertias are transferred to the elastic center, calculated by the program. The program prompts for the anchor movements at A1.
	R/S	AM2=	Prompts for the anchor movements at A2.
	R/S	I = 2.44	The program solves the inertia matrix with respect to the deflection matrix, resulting in the forces at A1. The forces are printed, as well as the moments at A1 and A2. The program automatically prompts with the display of the last elbow I factor.
0	ENTER	0	
0	ENTER	0	
0	shift A	I = 2.44	With the entry of this data the program calculates the moments at the first anchor. Note that the moments have the incorrect sign. The program displays the I factor of the last elbow analyzed.
1	R/S	OD = 1.00?	Changes the I factor used to 1.0. Prompts the user if the OD is from "base" data set 1.
	R/S		Program prints the stresses at Point 1.
10	ENTER	10	
0	ENTER	0	
0	shift A	I = 2.44	

Input	Function	Display	Comments
2.862	R/S	OD=1.00?	The program analyzes the stresses at the elbow in an X-orientation. This is an approximation of the stresses at the elbow entry point. The stresses are calculated using the value of Z as directed by the OD#. The orientation code determines the torsion and bending directions.
	R/S		
10	ENTER	10	These steps will correctly analyze the stresses at the 8" elbow at Point 4 in a Y-orientation, and at the final point, Point 6.
7	ENTER	7	
0	shift B	I = 2.44	
	R/S	OD=1.00?	
2	R/S		
20	ENTER	20	
7	ENTER	7	
0	shift A	I = 2.44	
1	R/S	OD=1.00?	
3	R/S		

Coding Form

Program Number HP-41CV-1 **Title** Thermal Expansion Analysis

Step/Line Key Entry	Key Code	Comments
01♦LBL "U"		Beginning of new problem.
02 CLRG		
03 1		
04 STO 07		
05♦LBL "R"		Beginning of a continuing problem that will change the "base" data.
06 CF 01		
07 CF 02		
08 0		
09 STO 11		
10 STO 03		
11 FIX 3		
12 SF 12		
13 "OD="		
14 PROMPT		Input of "base" data: OD, T, E, and e. Units for E are changed to million psi; units for e are changed to inches per foot.
15 STO 01		
16 ARCL 01		
17 PRA		
18 "T="		
19 PROMPT		
20 STO 02		
21 ARCL 02		
22 PRA		
23 "E="		
24 PROMPT		
25 STO 04		
26 ARCL 04		
27 PRA		
28 1 E6		
29 ST* 04		
30 "e="		
31 PROMPT		
32 STO 05		
33 ARCL 05		
34 PRA		
35 100		
36 ST/ 05		
37 ADV		Set pointers to store value of Z for pipe just input.
38 CF 12		
39 5		
40 STO 00		
41 47.1		
42 STO 10		
43 RCL 01		Calculate I of pipe.
44 X↑2		
45 X↑2		
46 RCL 01		
47 RCL 02		
48 2		
49 *		

Step/Line Key Entry	Key Code	Comments
50 -		Multiply I into R04 to get the EI value.
51 X↑2		
52 X↑2		
53 -		
54 PI		
55 *		
56 64		
57 /		
58 ST* 04		
59 RCL 01		Calculate Z of pipe.
60 /		
61 2		
62 *		
63♦LBL H		If the value found in R47, R48, R49 or R50 (directed by R10) is zero, the value of Z, calculated above, is stored in the register.
64 RCL IND 10		
65 X≠0?		
66 GTO 01		
67 RDN		
68 STO IND 10		
69 GTO "AA"		
70♦LBL 01		If there is already a Z-value in the register, the pointer is incremented. If the registers are all full, "nonexistent" is printed.
71 ISG 10		
72 CLX		
73 RDN		
74 DSE 00		
75 GTO H		
76 .		
77 1/X		
78♦LBL "AA"		Prompt for input of L.
79 FIX 0		
80 TONE 6		
81 "L"		
82 ARCL 07		
83 "⊢="		
84 PROMPT		
85♦LBL "X"		Input routine for an X-member. Accumulates ΔX in R17. Puts direction code in R25.
86 STO 13		
87 "⊢X="		
88 RCL 05		
89 *		
90 ST+ 17		
91 1		
92 STO 25		
93 20		Puts pointer in R44. Go to D.
94 STO 44		
95 GTO D		
96♦LBL "Y"		
97 STO 13		

Step/Line Key Entry	Key Code	Comments
98 "⊢Y="		Input routine for a Y-member. Accumulates ΔY in R18. Puts direction code in R25. Puts pointer in R44. Go to D.
99 RCL 05		
100 *		
101 ST+ 18		
102 2		
103 STO 25		
104 21		
105 STO 44		
106 GTO D		
107♦LBL "Z"		Input routine for a Z-member. Accumulates ΔZ in R19. Puts direction code in R25. Puts pointer in R44.
108 STO 13		
109 "⊢Z="		
110 RCL 05		
111 *		
112 ST+ 19		
113 3		
114 STO 25		
115 22		
116 STO 44		
117♦LBL D		If this is the last member, or the last of one set of base data, skip the prompt for R.
118 FS? 01		
119 GTO 10		
120 FS? 00		
121 GTO 10		
122 FIX 3		If no new value of R is input, meaning that "this" R is the same as the "last" R, the printout of R is skipped and Flag 3 is set.
123 ARCL 13		
124 PRA		
125 "R="		
126 CF 22		
127 CF 03		
128 PROMPT		
129 FC?C 22		
130 SF 03		
131 FS? 03		
132 GTO 10		
133 STO 03		
134 ARCL 03		
135 PRA		
136♦LBL 10		Set direction code for "this" member and store in R14.
137 ADV		
138 RCL 13		
139 SIGN		
140 RCL 25		
141 *		
142 STO 14		
143 RCL 11		First member of any "base" data set is sent to 11.
144 X=0?		
145 GTO 11		
146 ST+ IND 45		

Step/Line	Key Entry	Key Code	Comments
147	FIX 0		The length of the "last" member is accumulated into the register directed by R45. The end point coordinates of the "last" point are printed.
148	SF 12		
149	"PT"		
150	ARCL 07		
151	"⊢="		
152	PRA		
153	FIX 2		
154	CF 12		
155	CLA		
156	ARCL 20		
157	"⊢, "		
158	ARCL 21		
159	"⊢, "		
160	ARCL 22		
161	ACA		
162	ADV		
163	ADV		The straight piece length is calculated. If the member is a first or last member of any "base" data set, the length of the straight piece is compensated.
164	RCL 11		
165	ABS		
166	RCL 00		
167	-		
168	RCL 46		
169	-		
170	FS? 02		
171	GTO 05		
172	RCL 00		
173	+		
174♦	LBL 05		The c.g. coordinate alone the straight piece is calculated.
175	STO 15		
176	2		
177	/		
178	FS? 01		
179	GTO F		
180	FS? 00		
181	GTO F		
182	RCL 46		
183	+		
184♦	LBL F		
185	RCL 12		
186	SIGN		
187	*		
188	ST- IND 45		
189	SF 02		"Intermediate member" flag is set. Elbow # is calculated and stored in R16.
190	RCL 12		
191	RCL 14		
192	*		
193	STO 16		
194	GTO A		
195♦	LBL A		
196	26.1		The pointer is stored in R25. The direction code directs the program to correct straight inertia routine.
197	STO 25		
198	2		
199	RCL 12		
200	ABS		
201	X=Y?		
202	GTO 18		
203	X>Y?		
204	GTO 19		
205	RCL 15		Straight inertia controller for X-members. Calls all subroutines, directs program to the next routine.
206	STO 00		
207	XEQ 15		
208	XEQ "P"		
209	XEQ 15		
210	XEQ "Q"		
211	0		
212	STO 00		
213	1.3		
214	ST* 15		
215	XEQ 15		
216	1.3		
217	ST/ 15		
218	GTO 20		
219♦	LBL 18		Straight inertia controller for Y-members.
220	XEQ 16		
221	XEQ "P"		
222	0		
223	STO 00		
224	1.3		
225	ST* 15		
226	XEQ 15		
227	1.3		
228	ST/ 15		
229	RCL 15		
230	STO 00		
231	XEQ "Q"		
232	XEQ 15		
233	GTO 20		
234♦	LBL 19		Straight inertia controller for Z-members.
235	0		
236	STO 00		
237	1.3		
238	ST* 15		
239	XEQ 15		
240	XEQ "P"		
241	1.3		
242	ST/ 15		
243	RCL 15		
244	STO 00		
245	XEQ 16		
246	XEQ "Q"		
247	XEQ 16		
248	GTO 20		
249♦	LBL 15		Straight inertia routine. Performs all summations for an X-member in the Z-plane, an X-member in the Y-plane, and a Y-member in the X-plane. Also sums all torsion members in all planes.
250	XEQ 17		
251	RCL 15		
252	RCL 21		
253	X↑2		
254	*		
255	RCL 04		
256	/		
257	ST+ IND 25		
258	ISG 25		
259	RCL 15		
260	RCL 20		
261	X↑2		
262	*		
263	RCL 00		
264	3		
265	Y↑X		
266	12		
267	/		
268	+		
269	RCL 04		
270	/		
271	ST+ IND 25		
272	ISG 25		
273	RTN		
274♦	LBL 16		Straight inertia routine.
275	XEQ 17		
276	RCL 15		
277	RCL 21		
278	X↑2		Performs all summations for a Y-member in the Z-plane, a Z-member in the Y-plane, and a Z-member in the X-plane.
279	*		
280	RCL 15		
281	3		
282	Y↑X		
283	12		
284	/		
285	+		
286	RCL 04		
287	/		
288	ST+ IND 25		
289	ISG 25		
290	RCL 15		
291	RCL 20		
292	X↑2		
293	*		

Step/ Line	Key Entry	Key Code	Comments
294	RCL 04		
295	/		
296	ST+ IND 25		
297	ISG 25		
298	RTN		
299♦	LBL 17		Inertia subroutine. Performs the L, Lā, Lb̄ and Lab summations for Labels 15 and 16; a and b are the C.G. distances.
300	RCL 15		
301	RCL 04		
302	/		
303	ST+ IND 25		
304	ISG 25		
305	RCL 20		
306	*		
307	ST+ IND 25		
308	ISG 25		
309	RCL 15		
310	RCL 21		
311	*		
312	RCL 04		
313	/		
314	ST+ IND 25		
315	ISG 25		
316	RCL 20		
317	*		
318	ST+ IND 25		
319	ISG 25		
320	RTN		
321♦	LBL 20		The c.g. of the straight piece is moved back to the end point coordinates. Final member of any base data set is compensated.
322	XEQ "S"		
323	RCL 15		
324	2		
325	/		
326	FS? 01		
327	GTO G		
328	FS? 00		
329	GTO G		
330	RCL 46		
331	+		
332♦	LBL G		If the member is the final in the analysis, the program switches to the equation solver. If the bend radius is zero the elbow routine is skipped.
333	RCL 12		
334	SIGN		
335	*		
336	ST+ IND 45		
337	FS? 01		
338	GTO 30		
339	RCL 46		
340	X=0?		
341	GTO 11		
342	FS? 00		
343	GTO 12		
344	RCL 46		The end point coordinates are transformed to the c.g. coordinates of the elbow.
345	.363		
346	*		
347	RCL 12		
348	SIGN		
349	*		
350	ST- IND 45		
351	ABS		
352	RCL 14		
353	SIGN		
354	*		
355	ST+ IND 44		
356	26.1		The pointer is stored in R25. The The elbow # directs the program to the correct inertia subroutine.
357	STO 25		
358	3		
359	RCL 16		
360	ABS		
361	X=Y?		
362	GTO 24		
363	X>Y?		
364	GTO 25		
365	XEQ 21		Elbow routine. Main control for an X-Y bend. Calls all subroutines.
366	XEQ "P"		
367	XEQ 22		
368	XEQ "Q"		
369	XEQ 22		
370	GTO 26		
371♦	LBL 24		Elbow routine. Main control for an X-Z bend.
372	XEQ 22		
373	XEQ "P"		
374	XEQ 21		
375	XEQ "Q"		
376	XEQ 23		
377	GTO 26		
378♦	LBL 25		Elbow routine main control for a Y-Z bend.
379	XEQ 23		
380	XEQ "P"		
381	XEQ 23		
382	XEQ "Q"		
383	XEQ 21		
384	GTO 26		
385♦	LBL 21		Inertia summation routine. Performs all summations for an inplane elbow in any plane.
386	RCL 23		
387	RCL 04		
38	[illegible]		
389	ST+ IND 25		
390	ISG 25		
391	RCL 20		
392	*		
393	ST+ IND 25		
394	ISG 25		
395	RCL 23		
396	RCL 21		
397	*		
398	RCL 04		
399	/		
400	ST+ IND 25		
401	ISG 25		
402	RCL 20		
403	*		
404	RCL 09		
405	RCL 16		
406	SIGN		
407	*		
408	RCL 04		
409	/		
410	+		
411	ST+ IND 25		
412	ISG 25		
413	RCL 23		
414	RCL 21		
415	X↑2		
416	*		
417	RCL 08		
418	+		
419	RCL 04		
420	/		
421	ST+ IND 25		
422	ISG 25		
423	RCL 23		
424	RCL 20		
425	X↑2		
426	*		
427	RCL 08		
428	+		
429	RCL 04		
430	/		
431	ST+ IND 25		
432	ISG 25		
433	RTN		
434♦	LBL 22		Inertia summation routine. Performs all summations for the following out-plane bends: An X-Y elbow in the Y-plane, an X-Y elbow in the
435	XEQ E		
436	RCL 24		
437	RCL 21		
438	X↑2		
439	*		
440	RCL 04		

Step/Line	Key Entry	Key Code	Comments
441	/		X-plane, and an X-Z elbow in the Z-plane.
442	ST+ IND 25		
443	ISG 25		
444	RCL 24		
445	RCL 20		
446	X↑2		
447	*		
448	RCL 10		
449	+		
450	RCL 04		
451	/		
452	ST+ IND 25		
453	ISG 25		
454	RTN		
455♦LBL 23			Inertia summation routine. Performs all summations for the following outplane bends: An X-Z elbow in the X-plane, an X-Z elbow in the Y-plane, and a Y-Z elbow in the Y-plane.
456	XEQ E		
457	RCL 24		
458	RCL 21		
459	X↑2		
460	*		
461	RCL 10		
462	+		
463	RCL 04		
464	/		
465	ST+ IND 25		
466	ISG 25		
467	RCL 24		
468	RCL 20		
469	X↑2		
470	*		
471	RCL 04		
472	/		
473	ST+ IND 25		
474	ISG 25		
475	RTN		
476♦LBL E			Inertia summation subroutine. Sums the L, Lā, Lb̄, and Ixy values for both outplane summation routines; ā and b̄ are the c.g. coordinates for the bend.
477	RCL 24		
478	RCL 04		
479	/		
480	ST+ IND 25		
481	ISG 25		
482	RCL 20		
483	*		
484	ST+ IND 25		
485	ISG 25		
486	RCL 24		
487	RCL 21		
488	*		
489	RCL 04		
490	/		
491	ST+ IND 25		
492	ISG 25		
493	RCL 20		
494	*		
495	ST+ IND 25		
496	ISG 25		
497	RTN		
498♦LBL 26			The c.g. coordinates are returned to the end point coordinates.
499	XEQ "S"		
500	RCL 46		
501	.363		
502	*		
503	RCL 12		
504	SIGN		
505	*		
506	ST+ IND 45		
507	ABS		
508	RCL 14		
509	SIGN		
510	*		
511	ST- IND 44		
512♦LBL 11			Elbow data generator. If the next bend radius is the same as the last, this section is skipped. If R = 0, this section is also skipped. This section calculates K, $.149KR^3$, $.137KR^3$, and $.149(1.15)R^3$.
513	FS? 03		
514	GTO 12		
515	CF 03		
516	RCL 03		
517	X=0?		
518	GTO 12		
519	12		
520	*		
521	RCL 02		
522	*		
523	RCL 01		
524	RCL 02		
525	-		
526	2		
527	/		
528	X↑2		
529	/		
530	1.65		
531	X<>Y		
532	/		
533	STO 06		
534	.149		
535	RCL 03		Also calculates $\pi/2(K)(R)$ and $\pi/2(1.15)(R)$.
536	3		
537	Y↑X		
538	*		
539	*		
540	STO 08		
541	.92		
542	*		
543	STO 09		
544	1.15		
545	RCL 03		
546	3		
547	Y↑X		
548	*		
549	.149		
550	*		
551	STO 10		
552	PI		
553	2		
554	/		
555	RCL 03		
556	*		
557	RCL 06		
558	*		
559	STO 23		
560	LASTX		
561	/		
562	1.15		
563	*		
564	STO 24		
565♦LBL 12			Rolls "this" elbow radius to "last" register and "next" elbow radius to "this" register. If a new "base" data set is called for, the elbow I factor is calculated and printed, and the program is sent to label R for the new "base" data set.
566	RCL 46		
567	STO 00		
568	RCL 03		
569	STO 46		
570	FC?C 00		
571	GTO 27		
572	XEQ "Y"		
573	"I="		
574	FIX 3		
575	ARCL X		
576	PRA		
577	GTO "R"		
578♦LBL 27			The program is sent to prompt for a new L.
579	XEQ "N"		
580	GTO "AA"		
581♦LBL "W"			This section routes the program to the routines that lead to the input of a new "base" data set.
582	CLA		
583	SF 00		
584	CF 02		
585	GTO D		
586♦LBL "O"			Sends the program to the routines that
587	CLA		

Step/Line	Key Entry	Key Code	Comments
588	CF 02		do the final member summations and goes to the equation solver.
589	SF 01		
590	GTO D		
591	♦LBL 30		The program prompts for the data to be written onto magnetic cards. The last elbow I is stored in R07. Plane elastic centers are calculated from accumulated values of L and $\bar{L}$ in each plane.
592	CF 03		
593	WDTA		
594	XEQ "V"		
595	STO 07		
596	RCL 26		
597	ST/ 27		
598	ST/ 28		
599	RCL 32		
600	ST/ 33		
601	ST/ 34		
602	RCL 38		
603	ST/ 39		
604	ST/ 40		
605	RCL 28		
606	X↑2		Inertias are transferred. The program sums the inertias with respect to the first anchor at (0,0,0). The inertias are here transferred to the elastic centers of each plane.
607	RCL 26		
608	*		
609	ST- 30		
610	RCL 27		
611	X↑2		
612	RCL 26		
613	*		
614	ST- 31		
615	RCL 26		
616	RCL 27		
617	RCL 28		
618	*		
619	*		
620	RCL 29		
621	-		
622	STO 29		
623	RCL 34		
624	X↑2		
625	RCL 32		
626	*		
627	ST- 36		
628	RCL 33		
629	X↑2		
630	RCL 32		
631	*		
632	ST- 37		
633	RCL 32		
634	RCL 33		
635	RCL 34		
636	*		
637	*		
638	RCL 35		
639	-		
640	STO 35		
641	RCL 40		
642	X↑2		
643	RCL 38		
644	*		
645	ST- 42		
646	RCL 39		
647	X↑2		
648	RCL 38		
649	*		
650	ST- 43		
651	RCL 38		
652	RCL 39		
653	RCL 40		
654	*		
655	*		
656	RCL 41		
657	-		
658	STO 41		
659	FIX 2		Program prompts for the input of anchor movements at each anchor.
660	CLST		
661	SF 12		
662	"AM1="		
663	PROMPT		
664	PRA		
665	CLA		
666	CF 12		Each set is printed. The anchor movements at A1 are added to the summed totals from developed lengths. Anchor movements at A2 are subtracted from the accumulated totals.
667	ARCL Z		
668	"⊢ "		
669	ARCL Y		
670	"⊢ "		
671	ARCL X		
672	ACA		
673	ADV		
674	ST+ 19		
675	RDN		
676	ST+ 18		
677	RDN		
678	ST+ 17		
679	CLST		
680	SF 12		
681	"AM2="		
682	PROMPT		
683	PRA		
684	CLA		
685	CF 12		
686	ARCL Z		
687	"⊢ "		
688	ARCL Y		
689	"⊢ "		
690	ARCL X		
691	ACA		
692	ADV		
693	ST- 19		
694	RDN		
695	ST- 18		
696	RDN		
697	ST- 17		
698	RCL 30		The memories are readied for the matrix solver.
699	RCL 36		
700	+		
701	STO 25		
702	RCL 31		
703	RCL 42		
704	+		
705	STO 23		
706	RCL 37		
707	RCL 43		
708	+		
709	STO 24		
710	RCL 29		
711	STO 26		
712	RCL 35		
713	STO 32		
714	RCL 41		
715	STO 38		
716	1728		The inertias were summed in $ft^3/lb\text{-}in^2$. Here they are changed to $in^3/lb\text{-}in^2$.
717	ST* 26		
718	ST* 29		
719	ST* 32		
720	ST* 35		
721	ST* 38		
722	ST* 41		
723	ST* 23		
724	ST* 24		
725	ST* 25		
726	RCL 25		The simultaneous equations of the inertia matrix and the displacement matrix are solved.
727	ST/ 29		
728	ST/ 35		
729	ST/ 17		
730	RCL 26		
731	RCL 29		
732	*		
733	ST- 23		
734	RCL 26		

Step/Line	Key Entry	Key Code	Comments
735	RCL 35		
736	*		
737	ST- 41		
738	RCL 26		
739	RCL 17		
740	*		
741	ST- 18		
742	RCL 32		
743	RCL 29		
744	*		
745	ST- 38		
746	RCL 24		
747	RCL 32		
748	RCL 35		
749	*		
750	-		
751	STO 24		
752	RCL 19		
753	RCL 32		
754	RCL 17		
755	*		
756	-		
757	STO 19		
758	RCL 23		
759	ST/ 41		
760	ST/ 18		
761	1/X		
762	STO 23		
763	RCL 29		
764	RCL 41		
765	*		
766	ST- 35		
767	RCL 29		
768	RCL 18		
769	*		
770	ST- 17		
771	RCL 29		
772	RCL 23		
773	*		
774	CHS		
775	STO 29		
776	RCL 24		
777	RCL 38		
778	RCL 41		
779	*		
780	-		
781	STO 24		
782	RCL 19		
783	RCL 38		
784	RCL 18		
785	*		
786	-		
787	RCL 24		
788	/		
789	STO 19		
790	RCL 35		
791	RCL 19		
792	*		
793	ST- 17		
794	RCL 41		
795	RCL 19		
796	*		
797	ST- 18		
798	-1		The signs of the forces are changed to those at anchor 1 at (0,0,0).
799	ST* 17		
800	ST* 18		
801	ST* 19		
802	FIX 0		
803	ADV		System forces are printed. Control is sent to Label 36.
804	"FX1="		
805	ARCL 17		
806	PRA		
807	"FY1="		
808	ARCL 18		
809	PRA		
810	"FZ1="		
811	ARCL 19		
812	PRA		
813	FIX 2		
814	GTO 36		
815	♦LBL "K"		Stores the user-input values of stress point coordinates. Sets pointers for an X-oriented member, goes to moment and stress routine.
816	STO 10		
817	RDN		
818	STO 09		
819	RDN		
820	STO 08		
821	CF 01		
822	14		
823	STO 11		
824	15		
825	STO 12		
826	16		
827	STO 13		
828	"X"		
829	GTO B		
830	♦LBL "L"		Same as above for a Y-oriented member.
831	STO 10		
832	RDN		
833	STO 09		
834	RDN		
835	STO 08		
836	CF 01		
837	15		
838	STO 11		
839	14		
840	STO 12		
841	16		
842	STO 13		
843	"Y"		
844	GTO B		
845	♦LBL "M"		Same as above for a Z-oriented member.
846	STO 10		
847	RDN		
848	STO 09		
849	RDN		
850	STO 08		
851	CF 01		
852	16		
853	STO 11		
854	14		
855	STO 12		
856	15		
857	STO 13		
858	"Z"		
859	♦LBL B		User-input coordinates are printed along with the identifying orientation code (X, Y, or Z).
860	ADV		
861	"⊢="		
862	ARCL 08		
863	"⊢ "		
864	ARCL 09		
865	"⊢ "		
866	ARCL 10		
867	ACA		
868	ADV		
869	RCL 19		Calculate Mx at designated point.
870	RCL 39		
871	RCL 09		
872	-		
873	*		
874	RCL 18		
875	RCL 40		
876	RCL 10		
877	-		
878	*		
879	-		
880	STO 14		
881	RCL 17		

Step/ Line	Key Entry	Key Code	Comments
882	RCL 34		Calculate My at designated point.
883	RCL 10		
884	-		
885	*		
886	RCL 19		
887	RCL 33		
888	RCL 08		
889	-		
890	*		
891	-		
892	STO 15		
893	RCL 18		Calculate Mz at designated point.
894	RCL 27		
895	RCL 08		
896	-		
897	*		
898	RCL 17		
899	RCL 28		
900	RCL 09		
901	-		
902	*		
903	-		
904	STO 16		
905	FIX 0		Moment values are printed.
906	"MX="		
907	ARCL 14		
908	PRA		
909	"MY="		
910	ARCL 15		
911	PRA		
912	"MZ="		
913	ARCL 16		
914	PRA		
915	FIX 2		If the program is printing anchor moments, go to label 37.
916	ADV		
917	FS? 01		
918	GTO 37		
919	RCL 07		Prompts the user by displaying the I factor of the last elbow. If the user puts in another value, it is stored. The value used is printed.
920	"I="		
921	ARCL 07		
922	PROMPT		
923	CLA		
924	STO 06		
925	"I="		
926	ARCL 06		
927	PRA		
928	1		Asks the user if the OD is from "base" data set 1.
929	STO 05		
930	"OD="		
931	ARCL 05		The user agrees, or puts in the OD#. It is stored and printed.
932	"⊦?"		
933	PROMPT		
934	CLA		
935	STO 05		
936	"OD="		
937	ARCL 05		
938	PRA		
939	FIX 0		Pointer to correct Z value for stress is stored in R00.
940	46		
941	RCL 05		
942	+		
943	STO 00		
944	RCL IND 11		ST is calculated and stored in R01.
945	6		
946	*		
947	RCL IND 00		
948	/		
949	ABS		
950	STO 01		
951	2		SB is calculated, using the user-approved value of I. It is stored in R02.
952	*		
953	RCL IND 12		
954	RCL IND 13		
955	R-P		
956	12		
957	*		
958	RCL IND 00		
959	/		
960	RCL 06		
961	*		
962	STO 02		
963	RCL Z		SE is calculated and stored in R03.
964	R-P		
965	STO 03		
966	"ST="		ST, SB, and SE are printed.
967	ARCL 01		
968	PRA		
969	"SB="		
970	ARCL 02		
971	PRA		
972	"SE="		
973	ARCL 03		
974	PRA		
975	FIX 2		
976	STOP		
977	♦LBL 36		Coordinates for A1 are stored and the program is sent to the moment routine.
978	0		
979	STO 08		
980	STO 09		
981	STO 10		
982	"A1"		
983	GTO B		
984	♦LBL 37		Coordinates of the final point are stored and the signs of the forces are changed to get the correct sign for the moments at A2. Program is sent to moment routine.
985	CF 01		
986	RCL 20		
987	STO 08		
988	RCL 21		
989	STO 09		
990	RCL 22		
991	STO 10		
992	-1		
993	ST* 17		
994	ST* 18		
995	ST* 19		
996	"A2"		
997	GTO B		
998	♦LBL "P"		Rolls Z-plane coordinates to Y-plane coordinates.
999	RCL 21		
1000	RCL 22		
1001	STO 21		
1002	RDN		
1003	STO 22		
1004	RTN		
1005	♦LBL "Q"		Rolls Y-plane coordinates to X-plane coordinates.
1006	RCL 20		
1007	RCL 22		
1008	STO 20		
1009	RDN		
1010	STO 22		
1011	RTN		
1012	♦LBL "S"		Rolls X-plane coordinates back to Z-plane coordinates.
1013	RCL 22		
1014	RCL 20		
1015	RCL 21		
1016	STO 22		
1017	RDN		
1018	STO 21		
1019	RDN		
1020	STO 20		
1021	RTN		
1022	♦LBL "N"		Shifts all registers from "next" point data to "this" point data.
1023	RCL 13		
1024	STO 11		
1025	RCL 14		
1026	STO 12		
1027	RCL 44		
1028	STO 45		

Step/ Line	Key Entry	Key Code	Comments	Step/ Line	Key Entry	Key Code	Comments	Step/ Line	Key Entry	Key Code	Comments
1029	1										
1030	ST+ 07										
1031	♦LBL "Y"		Calculates the I value for the bend whose K factor is in memory.								
1032	1.65										
1033	RCL 06										
1034	X=0?										
1035	RTN										
1036	/										
1037	2										
1038	ENTER↑										
1039	3										
1040	/										
1041	Y↑X										
1042	.9										
1043	X<>Y										
1044	/										
1045	RTN										
1046	.END.										

Chapter 2

The Need for Thrust Blocks in Buried Thermoelastic Resin Pipes

Program TI-59-2: Thrust Blocks for Buried Pipe Fittings; Tees and Elbows

Introduction:

TI-59-2 is an analytical approach to the problem of thrust blocks for buried pipe fittings, specifically tees and 90-degree elbows. The method of analysis was developed by M. H. Anderson of Ameron Corporation. The program determines the maximum "safe" distance from a fitting to a thrust block, that the fitting may be buried without a block at all, or, finally, that the fitting needs an encapsulating thrust block to stay under the allowable stress. The analysis handles only 90-degree elbows and size-to-size tees and is designed for welded or epoxy joints.

Nomenclature:

Thirteen pieces of data must be input by the user:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- EL: Longitudinal modulus of elasticity (Mega psi)
- EC: Circumferential modulus of elasticity (Mega psi)
- e: Thermal growth rate (in/100 ft)
- P: Internal pressure (psig)
- KO: Coefficient of subgrade reaction (lbs/in^3)
- S: Allowance stress (psi)
- * MU: Poisson's ratio (longitudinal to circumferential
- GAM: Soil density (lbs/ft^3)
- H: Depth of soil cover (to top of pipe) (ft)
- FF: Friction factor of pipe to soil
- DEN: Density of pipe material (lbs/in^3)

Additionally, the program calculates the following data:

- ID: Pipe inside diameter (in)
- I: Pipe moment of inertia (in^4)
- W_W: Water weight per inch
- $\bar{P}$: Thrust force (lbs)
- A: Pipe area (in^2)
- W_P: Pipe weight per inch

Method:

The analysis uses beam-on-elastic-foundations equations to find the maximum allowable deflections and thrust forces for the two fittings, and then balances the deflections due to thermal expansion and pressure elongation against the deflections from friction resistance and soil bearing pressure. First the program calculates the foundation modulus:

$$\lambda = \sqrt[4]{\frac{(KO)(OD)}{(4)(EL)(I)}}$$

---

*The author of the paper that contains this analysis, Ameron document EB-24, developed the method for use with Reinforced Thermoelastic Resin pipe, which does not have homogeneous properties. Therefore, the value of Poisson's ratio is the value rated from the longitudinal to the circumferential direction. This value is "normalized" in the program by multiplying the value by the ratio of EL to EC. Pipe of this type usually exhibits values of 0.6 and greater. The user should be sure that the correct value is input.

Using this, the program calculates the maximum thrust allowed for the elbow and the tee:

$$\bar{P} = \left\{ S - \left| \frac{(P)(ID)}{(2)(T)} \frac{EL}{EC}(MU) - (e)(EL) \right| \right\} \frac{(8)(\lambda)(I)}{(OD)} \quad \text{for tees}$$

$$\bar{P} = \frac{S - \dfrac{(P)(ID)}{(4)(T)}}{\dfrac{(OD)}{(4)(I)(\lambda)} - \dfrac{1}{A}} \quad \text{for elbows}$$

From the above values, the maximum allowable displacement into the soil is calculated for each fitting:

$$y = \frac{(\bar{P})(\lambda)}{(2)(OD)(KO)} \quad \text{for tees}$$

$$y = \frac{(\bar{P})(\lambda)}{(OD)(KO)} \quad \text{for elbows}$$

Then the program calculates all the contributions to these values of y. For thermal expansion:

$$\Delta L_T = (e)(L), \text{ inches}$$

For pressure elongation:

$$\Delta L_P = \frac{(P)(ID)(L)}{(4)(T)(EL)}\left(1 - (2)(MU)\left(\frac{EL}{EC}\right)\right), \text{ inches}$$

For the thrust value:

$$\Delta L_{\bar{P}} = \frac{(\bar{P})(L)}{(A)(EL)}, \text{ inches}$$

For soil friction:

$$\Delta L_F = \frac{(F)(L)^2}{(2)(A)(EL)}, \text{ inches}$$

where

$$F = (FF)(W)$$

$$W = (2)(W_e) + (W_W) + (W_P)$$

$$W_e = \frac{GAM(H)(OD)}{144} = \text{weight of soil surcharge over pipe, lbs/in}$$

So, finally, the equation is:

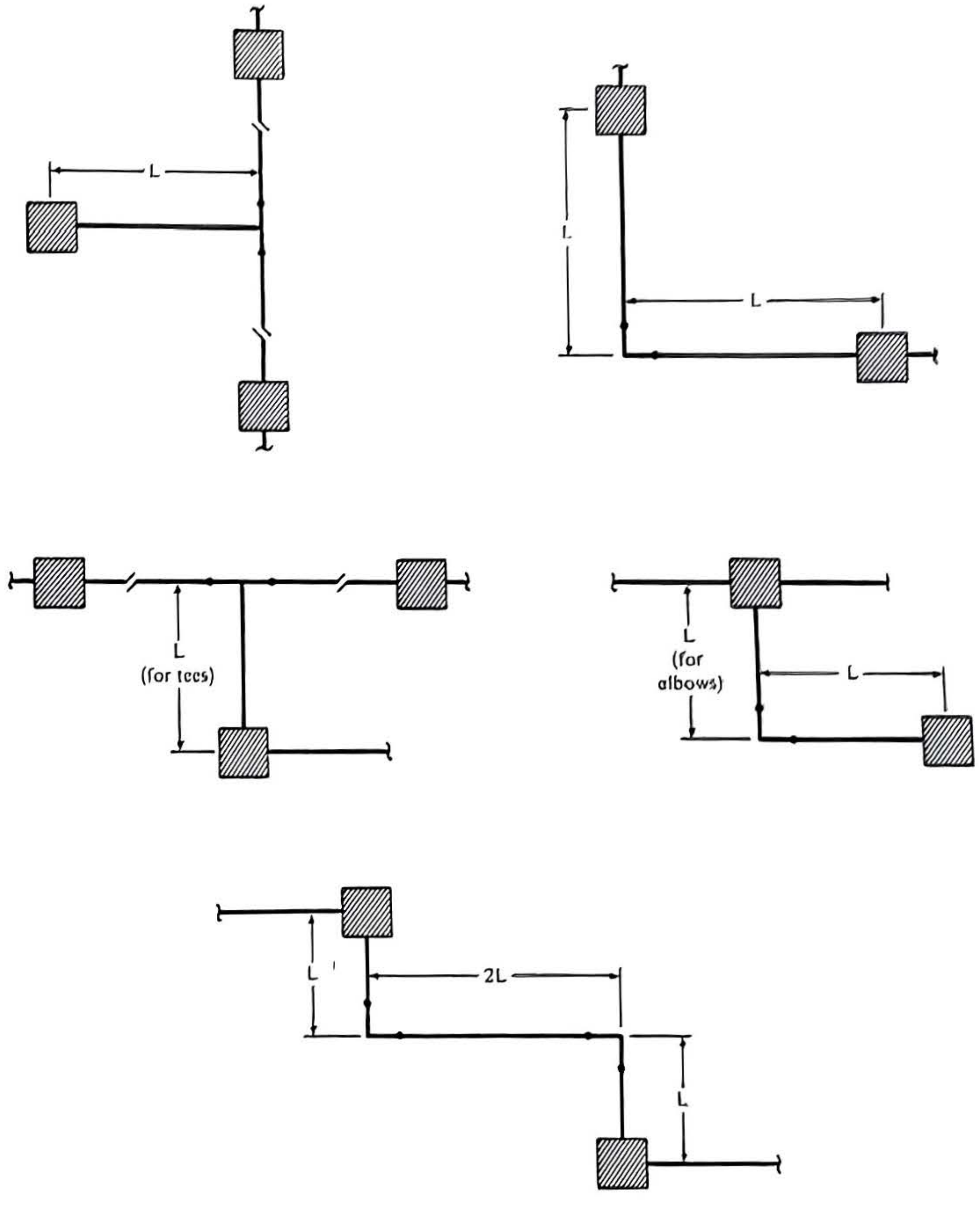
$$y = \Delta L_T + \Delta L_P - \Delta L_{\bar{P}} - \Delta L_F$$

If friction is not considered, the equation is a simple linear equation. If friction is considered, the equation becomes a quadratic in which the smaller root is the maximum "safe" length to an unblocked fitting. If the root is irrational, this means that the fitting does not need a thrust block, or that the "safe" length is unlimited. If the value of y is negative, the fitting will be overstressed without an encapsulating thrust block.

Limitations:

TI-59-2 only analyzes one pipe size and thickness at a time. The analysis is only developed for 90-degree elbows and size-to-size tees. The analysis always assumes that the pipe will be filled with water. The input value of allowable stress should be normalized with respect to any stress intensification factors.

Figure 2.1 Examples of Program TI-59-2



User Instructions

Program Number TI-59-2 **Title** Thrust Blocks for Buried Pipe Fittings

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards.		CLR	1, 2, or 3
2	Initialize program.		E	0
3	Input OD.	OD	A	OD
4	Input T.	T	A	T
5	Input EL.	EL	A	EL
6	Input EC.	EC	A	EC
7	Input e.	e	A	e
8	Input P.	P	A	P
9	Input KO.	KO	A	KO
10	Input S.	S	A	S
11	Input MU.	MU	A	MU
12	Input GAM.	GAM	A	GAM
13	Input H.	H	A	H
14	Input FF.	FF	A	FF
15	Input DEN.	DEN	A	DEN
16	Execute program.		B	Le11 TEE

Data Register Contents

REGISTER	DATA	REGISTER	DATA
00	-	30	
01	OD	31	
02	T	32	
03	EL	33	
04	EC	34	
05	e	35	
06	P	36	
07	KO	37	
08	S	38	
09	MU	39	
10	GAM	40	
11	H	41	
12	FF	42	
13	DEN	43	
14	A	44	27540202
15	Moment of inertia	45	27371717
16	λ	46	1199999.88
17	ID	47	3216
18	$\bar{P}$ TEE	48	37
19	$\bar{P}$ ell	49	1727
20	FF	50	1715
21	Δ ell	51	54
22	Δ TEE	52	33
23	"A"	53	2632
24	"B" ell	54	36
25	"B" TEE	55	3041
26	IND	56	221330
27	IND	57	23
28	Lell	58	2121
29	LTEE	59	161731

Example of a case where thrust blocks are not needed at either tees or elbows.

```
      4.5        OD
      0.18        T
      1.3        EL
      3.32       EC
      1.26        e
      100.        P
      280.       KD
      4000.       S
      0.64       MU
      110.      GAM
      4.          H
      0.4        FF
      0.065     DEN

   99999.99    Le11
   99999.99     TEE
```

Example of a case where the "safe" length to an anchor is some definite value.

```
      4.5        OD
      0.18        T
      1.24       EL
      3.2        EC
      1.56        e
      100.        P
      280.       KD
      4000.       S
      0.68       MU
      110.      GAM
      4.          H
      0.4        FF
      0.065     DEN

      14.75    Le11
      11.39     TEE
```

Example of a case where friction is *not* considered.

```
      4.5        OD
      0.18        T
      1.3        EL
      3.32       EC
      1.26        e
      100.        P
      280.       KD
      4000.       S
      0.64       MU
      110.      GAM
      4.          H
      0.         FF
      0.065     DEN

      12.16    Le11
      12.37     TEE
```

Example of a case where the fittings will be overstressed without a thrust block.

```
      4.5        OD
      0.18        T
      1.24       EL
      3.2        EC
      3.5         e
      1000.       P
      280.       KD
      100.        S
      0.68       MU
      110.      GAM
      4.          H
      0.4        FF
      0.065     DEN

      0.00     Le11
      0.00      TEE
```

Source Documentation

BURIED PIPE ANALYSIS
(REF. AMERON DOCUMENT EB-24)

OD = 4.5″
t = .18″
E1 = 1.24 EE6 psi
Ec = 3.2 EE6 psi
e = T = 1.56 in/100′
Pressure = 100 psig
K0 = 280 lbs/cubic inch (foundation modulus)
S = 4000 psi (allowable stress)
μ = 0.68 (poisson's ratio, longitudinal to circumferential)
δ = 110 lbs/cubic foot (soil density)
H = 4 ft. (depth of soil cover)
f = 0.4 (friction factor)
D = 0.065 lbs/cubic inch (density of pipe)

ID = 4.5 − 2(.18) = 4.14″
$I = ((4.5)^4 - (4.14)^4)(\pi)/64 = 5.709\ \text{in}^4$
$A = (4.5 - 0.18)(0.18)(\pi) = 2.443\ \text{in}^2$

$$\lambda = \text{beam characteristic} = \sqrt[4]{\frac{(280)(4.5)}{(4)(1.24\ \text{EE6})(5.709)}} = 0.082\ \text{in}$$

Find the maximum thrust loads on the pipe from all internal and external sources to stay within the allowable stress:

$$\frac{(4000) - \dfrac{(100)(4.14)}{(4)(0.18)}}{\dfrac{(4.5)}{(4)(5.709)(0.082)} - \dfrac{1}{(2.443)}} = 1709.521\ \text{lbs} = \bar{P}\ \text{for elbows}$$

$$\frac{\left\{4000 - \left|\dfrac{(100)(4.14)}{(2)(0.18)}\left(\dfrac{1.24}{3.20}\right)(.68) - \dfrac{(1.56)}{(1200)}(1.24\ \text{EE6})\right|\right\}}{\dfrac{(8)(0.082)(5.709)}{(4.5)}} = 2230.592\ \text{lbs} = \bar{P}\ \text{for tees}$$

Find the maximum allowed deflection of fittings from the values of $\bar{P}$:

$$\Delta ell = \frac{(1709.521)(0.082)}{(4.5)(280)} = 0.111\ \text{inches}$$

$$\Delta tee = \frac{(2230.592)(0.082)}{(2)(4.5)(280)} = 0.072\ \text{inches}$$

Calculate all contributions from various forces to the total Δ value:

$$\Delta temp = \frac{(1.56)}{(1200)}(L) = 0.00130\ (L)\ \text{inches}$$

$$\Delta pressure = \frac{(100)(4.14)(L)}{(4)(0.18)(1.24\ \text{EE6})}\left(1 - 2(0.68)\left(\frac{1.24}{3.20}\right)\right)$$
$$= 2.193\ \text{EE-4}\ (L)\ \text{inches}$$

$$\Delta\bar{P}_{ell} = \frac{(1709.521)(L)}{(2.443)(1.24\ \text{EE6})} = 0.00056\ (L)\ \text{inches}$$

$$\Delta\bar{P}_{tee} = \frac{(2230.592)(L)}{(2.443)(1.24\ \text{EE6})} = 0.00074\ (L)\ \text{inches}$$

$$\Delta friction = \frac{(F)(L^2)}{(2)(A)(E1)}$$

$F = f \cdot w$
$W = (2)(We) + (Wp) + (Ww)$
$We = (110)(4.5)(4)/(144) = 13.75$ lbs/in
$2We = (2)(13.75) = 27.50$ lbs/in
$Wp = (2.443)(0.065) = 0.159$ lbs/in
$Ww = ((4.14)^2(\pi)/4)(62.4)/1728) = 0.486$ lbs/in
$W = (27.5) + (0.159) + (0.486) = 28.145$ lbs/in
$F = (0.4)(28.145) = 11.258$ lbs/in

$$\Delta friction = \frac{(11.258)(L^2)}{(2)(2.443)(1.24\ \text{EE6})} = 1.858\ \text{EE-6}(L^2)\ \text{inches}$$

Solve the quadratic equation:

$$\frac{B - \sqrt{B - 4AC}}{2A} \quad \text{(smaller root)}$$

For both cases (elbows and tees) the "A" values is the contribution due to friction

So:

A = 1.858 EE-6

Elbows: C = 0.111
Tees: C = 0.078

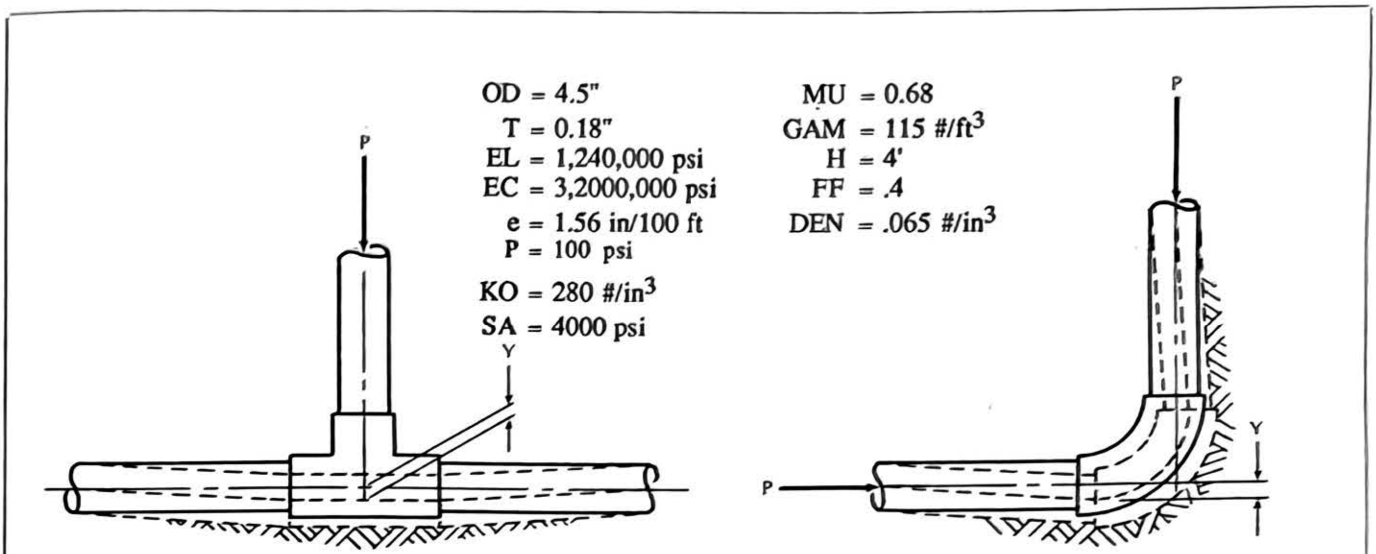
Elbows: B = (0.00130) + (2.193 EE-4) − (0.00056)
= 0.00095
Tees: B = (0.00130) + (2.193 EE-4) − (0.00074)
= 0.00078

$$L_{elbows} = \frac{(0.00095) - \sqrt{(0.00095) - (4)(1.858\ EE\text{-}6)(0.111)}}{(2)(1.858\ EE\text{-}6)} = 176.991'' = 14.749\ \text{ft}$$

$$L_{tees} = \frac{(0.00078) - \sqrt{(0.00078) - (4)(1.858\ EE\text{-}6)(0.078)}}{(2)(1.858\ EE\text{-}6)} = 136.654'' = 11.388\ \text{ft}$$

Sample Problem

Program: TI-59-2



(a) TEE (b) 90 DEGREE ELBOW

Step	Input	Key Stroke	Display	Printer		Comments
1		E	0			Initialize program.
2	4.5	A	4.5	4.5	OD	Store OD in R01; print.
3	.18	A	0.18	0.18	T	Store T in R02; print
4	1.24	A	1.24	1.24	EL	Store EL in R03; print.
5	3.2	A	3.2	3.2	EC	Store EC in R04; print.
6	1.56	A	1.56	1.56	e	Store e in R05; print.
7	100	A	100.	100.	P	Store P in R06; print.
8	280	A	280.	280.	KO	Store KO in R07; print.
9	4000	A	4000.	4000.	S	Store S in R08; print.
10	.68	A	0.68	0.68	MU	Store MU in R09; print.
11	110	A	110.	110.	GAM	Store GAM in R10; print.
12	4	A	4.	4.	H	Store H in R11; print.
13	.4	A	0.4	0.4	FF	Store FF in R12; print.
14	.065	A	0.065	0.065	DEN	Store DEN in R13; print.
15		B				
				14.75	Lell	
				11.39	TEE	The program calculates the foundation modulus and the maximum thrust force that can be applied to either the tee or the elbow. This is found using the input values of S, KO, OD, and EL. The program has also calculated the maximum allowable deflection for each fitting. Then the analysis finds the contributions to these values of delta from temperature, pressure, friction, and the maximum thrust force. Temperature and pressure work in one direction, while friction and the

Step	Input	Key Stroke	Display	Printer	Comments
					thrust force work in the opposite direction. If friction is not included in the analysis, the equation is a simple linear statement. If friction is considered, the equation becomes a quadratic, whose smaller root is the "safe" length. The program prints the two values of L, the value 99999.99 if a thrust block is not needed, or, finally, if the pipe will be overstressed without an encapsulat - ing thrust block, the printed value will be 0.00.

Coding Form

Program Number TI-59-2 **Title** Thrust Blocks for Buried Pipe Fittings

Loc	Code	Key	Comments
000	04	4	Initialize program: Set pointers for input routine, reset all flags to "OFF."
001	06	6	
002	42	STO	
003	29	29	
004	25	CLR	
005	42	STO	
006	00	00	
007	91	R/S	
008	76	LBL	
009	15	E	
010	81	RST	
011	76	LBL	Input routine. Uses R00 and R29 as pointers.
012	11	A	
013	32	X⇌T	
014	69	OP	
015	20	20	
016	01	1	
017	44	SUM	
018	29	29	
019	73	RC*	
020	29	29	
021	69	OP	
022	04	04	
023	32	X⇌T	
024	69	OP	
025	06	06	
026	72	ST*	
027	00	00	
028	91	R/S	
029	76	LBL	Subroutine: Solves quadratic equation. If the term $B^2 - 4AC$ is negative, an "infinite" length is returned to the main program.
030	16	A'	
031	73	RC*	
032	27	27	
033	33	X²	
034	75	−	
035	04	4	
036	65	×	
037	43	RCL	
038	23	23	
039	65	×	
040	73	RC*	
041	26	26	
042	94	+/−	
043	95	=	
044	77	GE	
045	38	SIN	
046	43	RCL	
047	46	46	
048	92	RTN	
049	76	LBL	If the quadratic is rational, the smaller root of the equation—the "safe" length—is returned to the main program.
050	38	SIN	
051	34	√X	
052	85	+	
053	73	RC*	
054	27	27	
055	94	+/−	
056	54	)	
057	55	÷	
058	02	2	
059	55	÷	

Loc	Code	Key	Comments
060	43	RCL	
061	23	23	
062	95	=	
063	92	RTN	
064	76	LBL	Main program. Clears test register. Adjusts units for EL, EC, and e.
065	12	B	
066	29	CP	
067	98	ADV	
068	01	1	
069	52	EE	
070	06	6	
071	49	PRD	
072	03	03	
073	49	PRD	
074	04	04	
075	01	1	
076	02	2	
077	00	0	
078	00	0	
079	35	1/X	
080	49	PRD	
081	05	05	
082	25	CLR	Calculates pipe area, pipe ID, and moment of inertia. ID is stored in R17. A is stored in R14. I is stored in R15.
083	43	RCL	
084	01	01	
085	33	X²	
086	42	STO	
087	14	14	
088	33	X²	
089	42	STO	
090	15	15	
091	43	RCL	
092	01	01	
093	75	−	
094	02	2	
095	65	×	
096	43	RCL	
097	02	02	
098	95	=	
099	42	STO	
100	17	17	
101	33	X²	
102	22	INV	
103	44	SUM	
104	14	14	
105	33	X²	
106	22	INV	
107	44	SUM	
108	15	15	
109	89	π	
110	49	PRD	
111	14	14	
112	49	PRD	
113	15	15	
114	04	4	
115	22	INV	
116	49	PRD	
117	14	14	
118	06	6	
119	04	4	

Loc	Code	Key	Comments
120	22	INV	
121	49	PRD	
122	15	15	
123	43	RCL	λ is calculated and stored in R16.
124	07	07	
125	65	×	
126	43	RCL	
127	01	01	
128	55	÷	
129	04	4	
130	55	÷	
131	43	RCL	
132	03	03	
133	55	÷	
134	43	RCL	
135	15	15	
136	95	=	
137	34	√X	
138	34	√X	
139	95	=	
140	42	STO	
141	16	16	
142	43	RCL	Maximum allowed thrust on a tee is calculated and stored in R18.
143	08	08	
144	75	−	
145	53	(	
146	43	RCL	
147	06	06	
148	65	×	
149	43	RCL	
150	17	17	
151	55	÷	
152	02	2	
153	55	÷	
154	43	RCL	
155	02	02	
156	65	×	
157	43	RCL	
158	03	03	
159	55	÷	
160	43	RCL	
161	04	04	
162	65	×	
163	43	RCL	
164	09	09	
165	75	−	
166	43	RCL	
167	05	05	
168	65	×	
169	43	RCL	
170	03	03	
171	54	)	
172	50	IxI	
173	54	)	
174	65	×	
175	08	8	
176	65	×	
177	43	RCL	
178	16	16	
179	65	×	

Loc	Code	Key	Comments
180	43	RCL	
181	15	15	
182	55	÷	
183	43	RCL	
184	01	01	
185	95	=	
186	42	STO	
187	18	18	
188	43	RCL	Maximum allowed thrust on an elbow is calculated and stored in R19.
189	08	08	
190	75	-	
191	43	RCL	
192	06	06	
193	65	×	
194	43	RCL	
195	17	17	
196	55	÷	
197	04	4	
198	55	÷	
199	43	RCL	
200	02	02	
201	54	)	
202	55	÷	
203	53	(	
204	43	RCL	
205	01	01	
206	55	÷	
207	04	4	
208	55	÷	
209	43	RCL	
210	15	15	
211	55	÷	
212	43	RCL	
213	16	16	
214	75	-	
215	43	RCL	
216	14	14	
217	35	1/X	
218	95	=	
219	42	STO	
220	19	19	
221	43	RCL	Fill load on pipe is calculated and stored in R20 (2We), lbs/in.
222	10	10	
223	65	×	
224	43	RCL	
225	11	11	
226	65	×	
227	43	RCL	
228	01	01	
229	55	÷	
230	07	7	
231	02	2	
232	95	=	
233	42	STO	
234	20	20	
235	43	RCL	Weight of water is added to R20, lbs./in.
236	17	17	
237	33	X²	
238	65	×	
239	89	π	

Loc	Code	Key	Comments
240	55	÷	
241	01	1	
242	01	1	
243	01	1	
244	95	=	
245	44	SUM	
246	20	20	
247	43	RCL	Weight of pipe is added to R20, lbs./in.
248	01	01	
249	33	X²	
250	75	-	
251	43	RCL	
252	17	17	
253	33	X²	
254	54	)	
255	65	×	
256	89	π	
257	55	÷	
258	04	4	
259	65	×	
260	43	RCL	
261	13	13	
262	95	=	
263	44	SUM	
264	20	20	
265	43	RCL	Friction factor is multiplied into R20.
266	12	12	
267	49	PRD	
268	20	20	
269	43	RCL	Maximum allowed deflection for a tee is calculated and stored in R22.
270	18	18	
271	65	×	
272	43	RCL	
273	16	16	
274	55	÷	
275	43	RCL	
276	01	01	
277	55	÷	
278	43	RCL	
279	07	07	
280	55	÷	
281	02	2	
282	95	=	
283	42	STO	
284	22	22	
285	65	×	Maximum allowed deflection for an elbow is calculated and stored in R21.
286	02	2	
287	55	÷	
288	43	RCL	
289	18	18	
290	65	×	
291	43	RCL	
292	19	19	
293	95	=	
294	42	STO	
295	21	21	
296	77	GE	If Δell is less than zero, Flag 1 is set. If ΔTEE is less than zero, Flag 2 is set.
297	70	RAD	
298	86	STF	
299	01	01	

Loc	Code	Key	Comments
300	76	LBL	
301	70	RAD	
302	43	RCL	
303	22	22	
304	77	GE	
305	80	GRD	
306	86	STF	
307	02	02	
308	76	LBL	The friction term for the quadratic equation is calculated and stored in R23. This is A.
309	80	GRD	
310	43	RCL	
311	20	20	
312	55	÷	
313	02	2	
314	55	÷	
315	43	RCL	
316	14	14	
317	55	÷	
318	43	RCL	
319	03	03	
320	95	=	
321	94	+/-	
322	42	STO	
323	23	23	
324	43	RCL	The thrust term of the value B for tees is calculated and stored in R24.
325	19	19	
326	55	÷	
327	43	RCL	
328	14	14	
329	55	÷	
330	43	RCL	
331	03	03	
332	95	=	
333	94	+/-	
334	42	STO	
335	24	24	
336	55	÷	Thrust term for B is calculated for elbows and stored in R25.
337	43	RCL	
338	19	19	
339	65	×	
340	43	RCL	
341	18	18	
342	95	=	
343	42	STO	
344	25	25	
345	43	RCL	The pressure term for the value B is calculated and added to the thermal term. This sum is added to R24 and R25.
346	06	06	
347	65	×	
348	43	RCL	
349	17	17	
350	55	÷	
351	04	4	
352	55	÷	
353	43	RCL	
354	02	02	
355	55	÷	
356	43	RCL	
357	03	03	
358	65	×	
359	53	(	

Loc	Code	Key	Comments
360	01	1	
361	75	−	
362	02	2	
363	65	×	
364	43	RCL	
365	09	09	
366	65	×	
367	43	RCL	
368	03	03	
369	55	÷	
370	43	RCL	
371	04	04	
372	54	)	
373	85	+	
374	43	RCL	
375	05	05	
376	95	=	
377	44	SUM	
378	24	24	
379	44	SUM	
380	25	25	
381	02	2	Load pointers for quadratic subroutine.
382	04	4	
383	42	STO	
384	27	27	
385	02	2	
386	01	1	
387	42	STO	
388	26	26	
389	43	RCL	If the friction factor is zero, then the safe length is a linear equation. Each value of Δ is divided by its corresponding B term. Lell is stored in R28, TEE is in R29.
390	12	12	
391	22	INV	
392	67	EQ	
393	30	TAN	
394	43	RCL	
395	21	21	
396	55	÷	
397	43	RCL	
398	24	24	
399	95	=	
400	42	STO	
401	28	28	
402	43	RCL	
403	22	22	
404	55	÷	
405	43	RCL	
406	25	25	
407	95	=	
408	42	STO	
409	29	29	
410	61	GTO	
411	14	D	
412	76	LBL	If the friction is considered, the quadratic is solved for each value of L, for elbows and tees.
413	30	TAN	
414	16	A'	
415	42	STO	
416	28	28	
417	01	1	
418	44	SUM	
419	26	26	
420	44	SUM	
421	27	27	
422	16	A'	
423	42	STO	
424	29	29	
425	76	LBL	If Flag 1 is set, then Lell becomes zero (overstressed). If Flag 2 is set, LTEE becomes zero (overstressed).
426	14	D	
427	22	INV	
428	87	IFF	
429	01	01	
430	48	EXC	
431	00	0	
432	42	STO	
433	28	28	
434	76	LBL	
435	48	EXC	
436	22	INV	
437	87	IFF	
438	02	02	
439	49	PRD	
440	00	0	
441	42	STO	
442	29	29	
443	76	LBL	The values of L are converted to feet.
444	49	PRD	
445	01	1	
446	02	2	
447	35	1/X	
448	49	PRD	
449	28	28	
450	49	PRD	
451	29	29	
452	43	RCL	Lell is printed.
453	44	44	
454	69	OP	
455	04	04	
456	58	FIX	
457	02	02	
458	43	RCL	
459	28	28	
460	69	OP	
461	06	06	
462	43	RCL	TEE is printed; the program is reset.
463	45	45	
464	69	OP	
465	04	04	
466	43	RCL	
467	29	29	
468	69	OP	
469	06	06	
470	98	ADV	
471	98	ADV	
472	98	ADV	
473	98	ADV	
474	22	INV	
475	58	FIX	
476	81	RST	

Buried Pipe Analysis

Pipe outside diameter (in)
Pipe wall thickness (in)
Longitudinal modulus of elasticity (Mega psi)
Circumferential modulus of elasticity (mega psi)
Thermal growth rate (in/100 ft)
Internal pressure (psig)
Coefficient of subgrade reaction (lbs/in^3)
Allowable stress (psi)
Poisson's ratio (longitudinal to circumferential)
Soil density (lbs/ft^3)
Depth of soil cover (to top of pipe) (ft)
Friction factor of pipe to soil
Density of pipe material (lbs/in^3)

"Safe" length from an anchor to an elbow (ft)
"Safe" length from an anchor to a tee (ft)

Program HP-41CV-2: Thrust Blocks For Buried Pipe Fittings; Tees and Elbows

Introduction:

HP-41CV-2 is an analytical approach to the problem of thrust blocks for buried pipe fittings, specifically tees and 90-degree elbows. The method of analysis was developed by M. H. Anderson of Ameron Corporation. The program determines the maximum "safe" distance from a fitting to a thrust block, that the fitting may be buried without a block at all, or, finally, that the fitting needs an encapsulating thrust block to stay under the allowable stress. The analysis handles only 90-degree elbows and size-to-size tees and is designed for welded or epoxy joints.

Nomenclature:

There are thirteen pieces of data that must be input by the user. They are:

- OD: Pipe outside diameter (in)
- WALL T: Pipe wall thickness (in)
- E1: Longitudinal modulus of elasticity (Mega psi)
- Ec: Circumferential modulus of elasticity (Mega psi)
- e: Thermal growth rate (in/100 ft)
- PRESS: Internal pressure (psig)
- KO: Coefficient of subgrade reaction (lbs/in^3)
- * POISSN: Poisson's ratio (longitudinal to circumferential)
- d.SOIL: Density of the soil (lbs/ft^3)
- COVER: Depth of soil cover (ft)
- FR.FAC: Friction factor of pipe to soil
- d.PIPE: Density of pipe material (lbs/in^3)
- Sa: Allowable stress (psi)

Additionally, the program calculates the following data:

- ID: Pipe inside diameter (in)
- I: Pipe moment of inertia (in^4)
- W_w: Water weight per inch
- $\bar{P}$: Thrust force (lbs)
- A: Pipe area (in^2)
- W_P: Pipe weight per inch

Method:

The analysis uses beam-on-elastic-foundations equations to find the maximum allowable deflections and thrust forces for the two fittings, and then balances the deflections due to thermal expansion and pressure elongation against the deflection from friction resistance and soil bearing pressure. First, the program calculates the foundation modulus:

$$\lambda = \sqrt[4]{\frac{(KO)(OD)}{(4)(E1)(I)}}$$

Using this, the program calculates the maximum thrust allowed for the elbow and the tee:

$$\bar{P} = \left\{ Sa - \left| \frac{(PRESS)(ID)}{(2)(WALL\ T)} \frac{E1}{Ec} (POISSN) - (e)(E1) \right| \right\} \times \frac{(8)(\lambda)(I)}{(OD)} \qquad \text{for tees}$$

$$\bar{P} = \frac{Sa - \dfrac{(PRESS)(ID)}{(4)(WALL\ T)}}{\dfrac{(OD)}{(4)(I)(\lambda)} - \dfrac{1}{A}} \qquad \text{for elbows}$$

From the above values, the maximum allowable displacement into the soil is calculated for each fitting:

$$y = \frac{(\bar{P})(\lambda)}{(2)(OD)(KO)} \qquad \text{for tees}$$

$$y = \frac{(\bar{P})(\lambda)}{(OD)(KO)} \qquad \text{for elbows}$$

Then the program calculates all the contributions to these values of y. For thermal expansion:

$$\Delta L_T = (e)(L), \text{ inches}$$

For pressure elongation:

---

*The author of the paper that contains this analysis, Ameron Document EB-24, developed the method for use with Reinforced Thermoelastic Resin pipe, which does not have homogeneous properties. Therefore, the value of Poisson's ratio is the value rated from the longitudinal to the circumferential direction. This value is "normalized" in the program by multiplying the value by the ratio of E1 to Ec. Pipe of this type usually exhibits values of 0.6 and greater. The user should be sure that the correct value is input.

$$\Delta L_P = \frac{(PRESS)(ID)(L)}{(4)(WALL\ T)(E1)} \left(1 - (2)(POISSN)\left(\frac{EL}{EC}\right)\right), \text{ inches}$$

For the thrust value:

$$\Delta L_{\bar{P}} = \frac{(\bar{P})(L)}{(A)(E1)}, \text{ inches}$$

For soil friction:

$$\Delta L_F = \frac{(F)(L)^2}{(2)(A)(E1)}, \text{ inches}$$

where

$$F = (FR.FAC)(W)$$

$$W = (2)(W_c) + (W_W) + (W_P)$$

$$W_c = \frac{(d.SOIL)(COVER)(OD)}{144} = \text{weight of soil surcharge over pipe, lbs/in}$$

So, finally, the equation is:

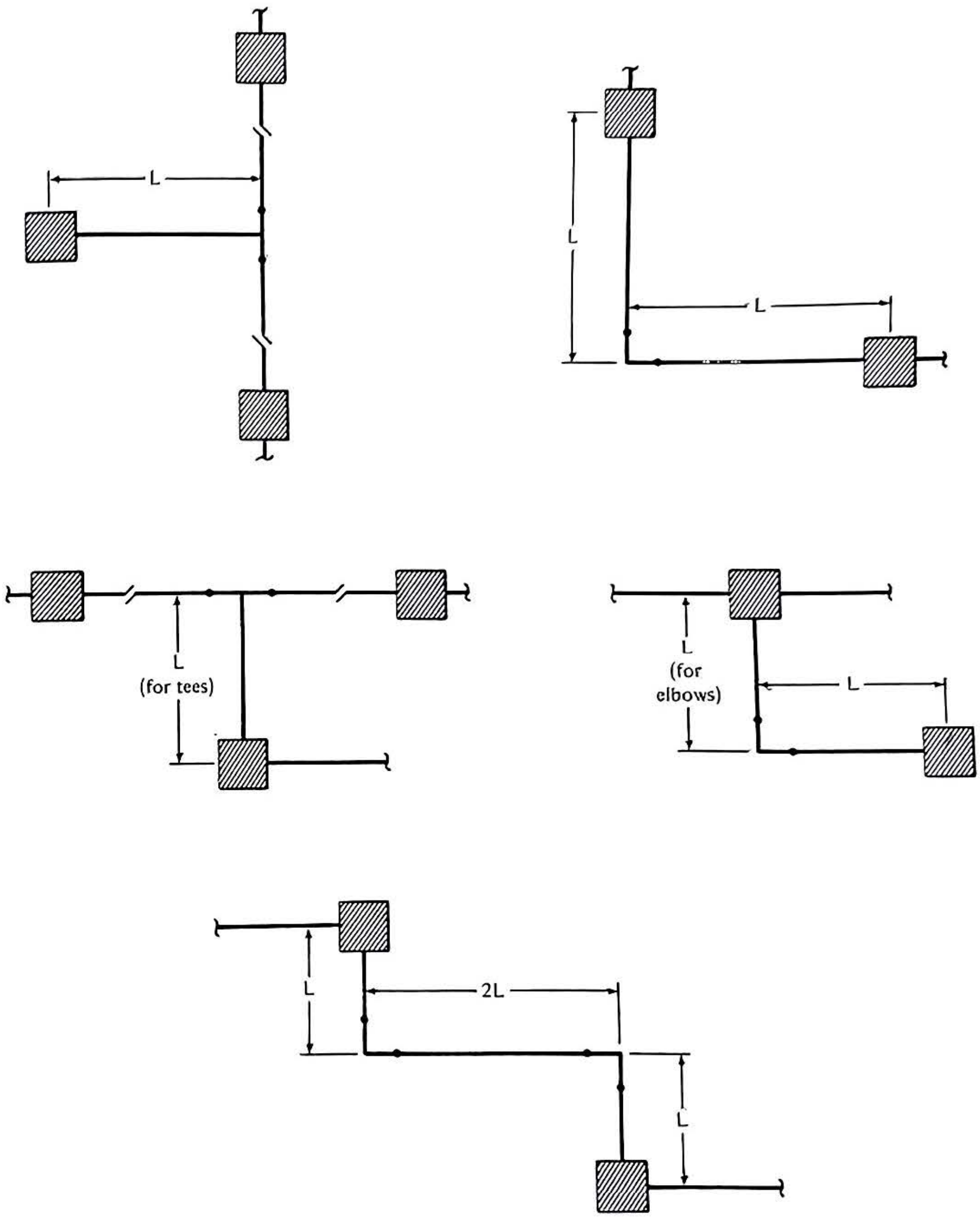
$$y = \Delta L_T + \Delta L_P - \Delta L_{\bar{P}} - \Delta L_F$$

If friction is not considered, the equation is a simple linear equation. If friction is considered, the equation becomes a quadratic where the small root is the maximum "safe" length to an unblocked fitting. If the root is irrational, this means that the fitting does not need a thrust block, or the "safe" length is unlimited. If the value of y is negative, this indicates that the fitting will be overstressed without an encapsulating thrust block.

Limitations:

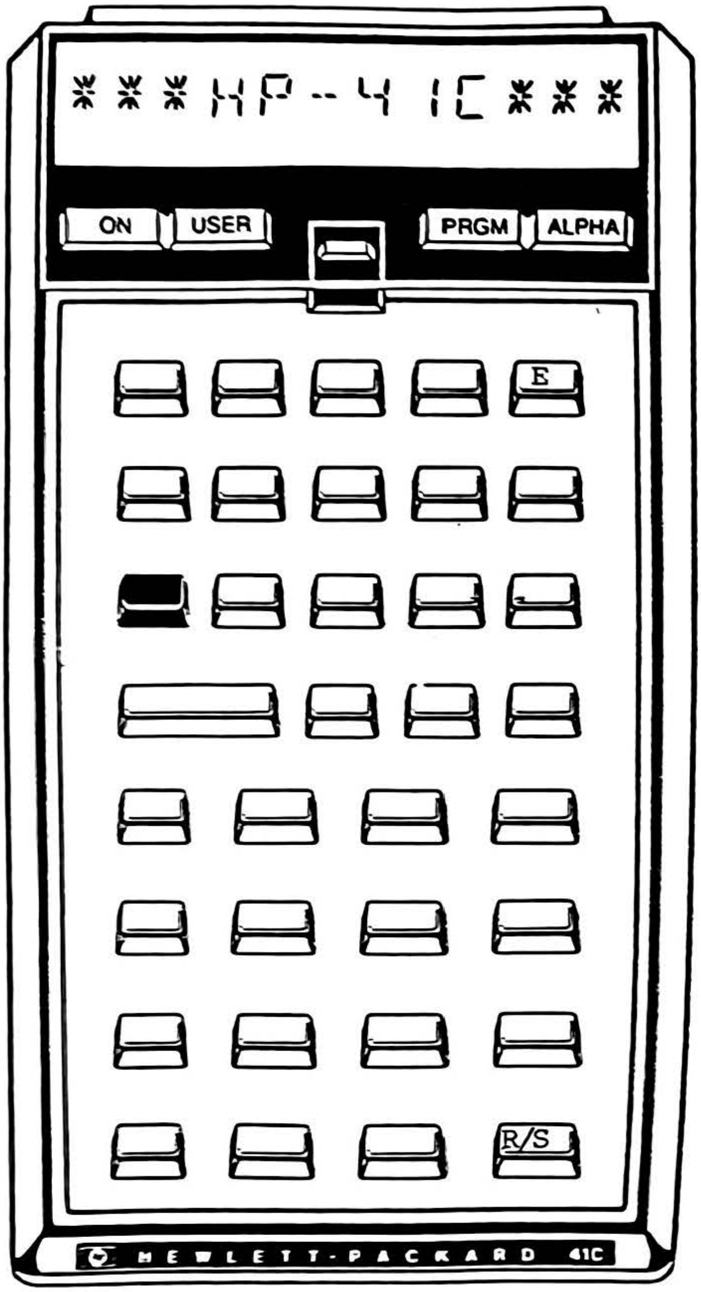
HP-41CV-2 only analyzes one pipe size and thickness at a time. The analysis is only developed for 90-dgree elbows and size-to-size tees. The analysis always assumes that the pipe will be filled with water. The input value of allowable stress should be normalized with respect to any stress intensification factors.

Figure 2.2 Examples of HP-41CV-2 Program

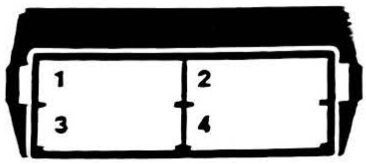


Keyboard Card Labeling

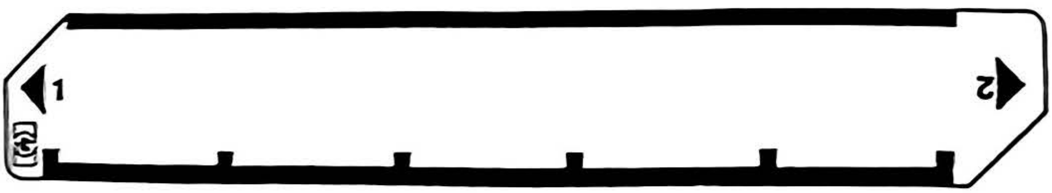
KEYBOARD



SYSTEM
CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-2 **Title** Thrust Blocks for Buried Pipe Fittings

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards (six sides).			
2	Initialize program.		E	OD=
3	Input OD	OD	R/S	WALL T=
4	Input WALL T.	WALL T	R/S	E1=
5	Input E1.	E1	R/S	Ec=
6	Input Ec.	Ec	R/S	e=
7	Input e.	e	R/S	PRESS=
8	Input PRESS.	PRESS	R/S	KO=
9	Input KO.	KO	R/S	Sa=
10	Input Sa.	Sa	R/S	POISSN=
11	Input POISSN.	POISSN	R/S	d.SOIL=
12	Input d.SOIL.	d.SOIL	R/S	COVER=
13	Input COVER.	COVER	R/S	FR.FAC=
14	Input FR.FAC.	FR.FAC	R/S	d.PIPE=
15	Input d.PIPE.	d.PIPE	R/S	
				90° ELBOW
				Safe L
				TEE
				Safe L

Registers, Flags, Assignments

Program Number HP-41CV-2 **Title** Thrust Blocks for Buried Pipe Fittings

DATA REGISTERS

00	POINTER
01	OD
02	WALL T
03	El
04	Ec
05	e
06	PRESS
07	KO
08	Sa
09	POISSN
10	d.SOIL
11	COVER
12	FR.FAC
13	d.PIPE
14	Pipe area
15	Moment of inertia
16	λ
17	Inside diameter
18	$\overline{P}$ (tee)
19	$\overline{P}$ (elbow)
20	FR.FAC
21	Δell
22	Δtee
23	"A"
24	"B" for elbows
25	"B" for tees
26	pointer
27	pointer
28	Safe L for elbows
29	Safe L for tees
30	
31	
32	
33	
34	
35	
36	
37	
38	

DATA REGISTERS

39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates
1	C	OVERSTRESSED ELBOW	
2	C	OVERSTRESSED TEE	

ASSIGNMENTS

Label	Key	Function	Key
RTR	E (15)		

Example of an analysis where friction is *not* considered.

```
OD= 4.500
WALL  T= 0.100
E1= 1.300
Ec= 3.320
e= 1.260
PRESS= 100.000
KO= 280.000
Sa= 4,000.000
POISSN= 0.640
d.SOIL= 110.000
COVER= 4.000
FR.FAC= 0.000
d.PIPE= 0.065

  90" ELBOW

     SAFE L= 12.160'

     TEE

     SAFE L= 12.372'
```

Example of a situation where thrust blocks are not needed on either elbows or tees.

```
OD= 4.500
WALL  T= 0.100
E1= 1.300
Ec= 3.320
e= 1.260
PRESS= 100.000
KO= 280.000
Sa= 4,000.000
POISSN= 0.640
d.SOIL= 110.000
COVER= 4.000
FR.FAC= 0.400
d.PIPE= 0.065

  90" ELBOW

UNLIMITED

        TEE

UNLIMITED
```

Example of a case where the safe length to an unblocked fitting is some definite value.

```
OD= 4.500
WALL  T= 0.100
E1= 1.240
Ec= 3.200
e= 1.560
PRESS= 100.000
KO= 280.000
Sa= 4,000.000
POISSN= 0.680
d.SOIL= 110.000
COVER= 4.000
FR.FAC= 0.400
d.PIPE= 0.065

  90" ELBOW

     SAFE L= 14.749'

     TEE

     SAFE L= 11.387'
```

Example of a case where the piping is overstressed without a thrust block

```
OD= 4.500
WALL  T= 0.100
E1= 1.240
Ec= 3.200
e= 3.500
PRESS= 1,000.000
KO= 280.000
Sa= 100.000
POISSN= 0.680
d.SOIL= 110.000
COVER= 4.000
FR.FAC= 0.400
d.PIPE= 0.065

  90" ELBOW

OVER
STRESSED

        TEE

OVER
STRESSED
```

BURIED PIPE ANALYSIS
(REF. AMERON DOCUMENT EB-24)

OD = 4.5"
t = .18"
El = 1.24 EE6 psi
Ec = 3.2 EE6 psi
e = T = 1.56 in/100'
Pressure = 100 psig
K0 = 280 lbs/cubic inch (foundation modulus)
S = 4000 psi (allowable stress)
μ = 0.68 (poisson's ratio, longitudinal to circumferential)
δ = 110 lbs/cubic foot (soil density)
H = 4 ft. (depth of soil cover)
f = 0.4 (friction factor)
D = 0.065 lbs/cubic inch (density of pipe)

$ID = 4.5 - 2(.18) = 4.14''$
$I = ((4.5)^4 - (4.14)^4)(\pi)/64 = 5.709 \text{ in}^4$
$A = (4.5 - 0.18)(0.18)(\pi) = 2.443 \text{ in}^2$

$$\lambda = \text{beam characteristic} = \sqrt[4]{\frac{(280)(4.5)}{(4)(1.24 \text{ EE6})(5.709)}} = 0.082 \text{ in}$$

Find the maximum thrust loads on the pipe from all internal and external sources to stay within the allowable stress:

$$\frac{(4000) - \dfrac{(100)(4.14)}{(4)(0.18)}}{\dfrac{(4.5)}{(4)(5.709)(0.082)} - \dfrac{1}{(2.443)}} = 1709.521 \text{ lbs} = \bar{P} \text{ for elbows}$$

$$\left\{4000 - \left|\frac{(100)(4.14)}{(2)(0.18)}\left(\frac{1.24}{3.20}\right)(.68) - \frac{(1.56)}{(1200)}(1.24 \text{ EE6})\right|\right\}$$
$$\frac{(8)(0.082)(5.709)}{(4.5)} = 2230.592 \text{ lbs} = \bar{P} \text{ for tees}$$

Find the maximum allowed deflection of fittings from the values of $\bar{P}$:

$$\Delta ell = \frac{(1709.521)(0.082)}{(4.5)(280)} = 0.111 \text{ inches}$$

$$\Delta tee = \frac{(2230.592)(0.082)}{(2)(4.5)(280)} = 0.072 \text{ inches}$$

Calculate all contributions from various forces to the total Δ value:

$$\Delta temp = \frac{(1.56)}{(1200)}(L) = 0.00130\,(L) \text{ inches}$$

$$\Delta pressure = \frac{(100)(4.14)(L)}{(4)(0.18)(1.24 \text{ EE6})}\left(1 - 2(0.68)\left(\frac{1.24}{3.20}\right)\right)$$
$$= 2.193 \text{ EE-4 } (L) \text{ inches}$$

$$\Delta\bar{P}_{ell} = \frac{(1709.521)(L)}{(2.443)(1.24 \text{ EE6})} = 0.00056\,(L) \text{ inches}$$

$$\Delta\bar{P}_{tee} = \frac{(2230.592)(L)}{(2.443)(1.24 \text{ EE6})} = 0.00074\,(L) \text{ inches}$$

$$\Delta friction = \frac{(F)(L^2)}{(2)(A)(E1)}$$

F = F = f · w
W = (2)(We) + (Wp) + (Ww)
We = (110)(4.5)(4)/(144) = 13.75 lbs/in
2We = (2)(13.75) = 27.50 lbs/in
Wp = (2.443)(0.065) = 0.159 lbs/in
$Ww = ((4.14)^2(\pi)/4)(62.4)/1728) = 0.486$ lbs/in
W = (27.5) + (0.159) + (0.486) = 28.145 lbs/in
F = (0.4)(28.145) = 11.258 lbs/in

$$\Delta friction = \frac{(11.258)(L^2)}{(2)(2.443)(1.24 \text{ EE6})} = 1.858 \text{ EE-6}(L^2) \text{ inches}$$

Solve the quadratic equation:

$$\frac{B - \sqrt{B - 4AC}}{2A} \quad \text{(smaller root)}$$

For both cases (elbows and tees) the "A" values is the contribution due to friction

So:

A = 1.858 EE-6

Elbows: C = 0.111
Tees: C = 0.078

Elbows: B = (0.00130) + (2.193 EE-4) − (0.00056)
= 0.00095
Tees: B = (0.00130) + (2.193 EE-4) − (0.00074)
= 0.00078

$$L_{elbows} = \frac{(0.00095) - \sqrt{(0.00095) - (4)(1.858\ \text{EE-6})(0.111)}}{(2)(1.858\ \text{EE-6})} = 176.991'' = 14.749\ \text{ft}$$

$$L_{tees} = \frac{(0.00078) - \sqrt{(0.00078) - (4)(1.858\ \text{EE-6})(0.078)}}{(2)(1.858\ \text{EE-6})} = 136.654'' = 11.388\ \text{ft}$$

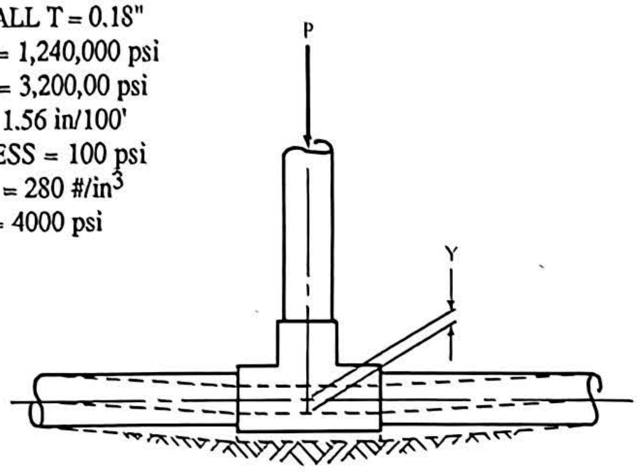
Sample Problem

Program: HP-41CV-2 Title Thrust Blocks for Buried Pipe Fittings

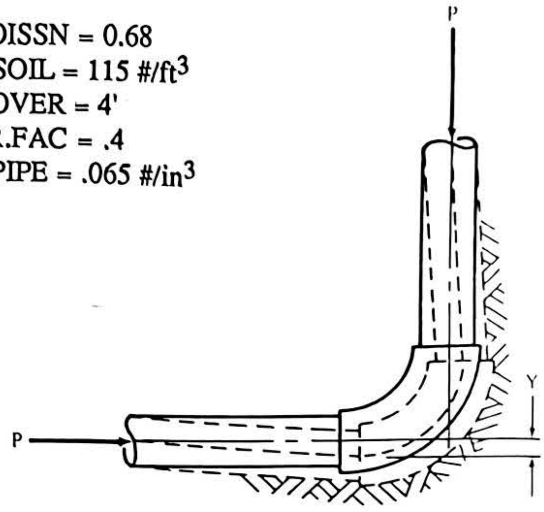
Sample Problem (Sketch if Desired)

OD = 4.5"
WALL T = 0.18"
El = 1,240,000 psi
Ec = 3,200,00 psi
e = 1.56 in/100'
PRESS = 100 psi
KO = 280 #/in^3
Sa = 4000 psi

POISSN = 0.68
d.SOIL = 115 #/ft^3
COVER = 4'
FR.FAC = .4
d.PIPE = .065 #/in^3



(a) TEE



(b) 90 DEGREE ELBOW

Input	Function	Display	Comments
	E	OD=	Initializes program, prompts for OD.
4.5	R/S	WALL T=	Stores OD in R01; prompts for WALL T.
.18	R/S	E1=	Stores WALL T in R02; prompts for E1
1.24	R/S	Ec=	Stores E1 in R03; prompts for Ec.
3.2	R/S	e=	Stores Ec in R04; prompts for e.
1.56	R/S	PRESS=	Stores e in R05; prompts for PRESS.
100	R/S	KO=	Stores PRESS in R06; prompts for KO.
280	R/S	Sa=	Stores KO in R07; prompts for Sa.
4000	R/S	POISSN=	Stores Sa in R08; prompts for POISSN.
.68	R/S	d.SOIL	Stores POISSN in R09; prompts for d.SOIL.
110	R/S	COVER=	Stores d.SOIL in R10; prompts for COVER.
4	R/S	FR.FAC=	Stores COVER in R11; prompts for FR.FAC.
.4	R/S	d.PIPE=	Stores FR.FAC in R12; prompts for d.PIPE.
.065	R/S	90° ELBOW	From the values of OD, KO, and Sa the program calculates the allowable deflection for the tee and the elbow,
		SAFE L = 14.749'	that will allow the fitting to remain under the allowable stress value.
		TEE SAFE L = 11.387'	These values are based on the maxmum load that can be allowed ($\bar{P}$). Then the program begins to figure the contribution to this delta from the thermal expansion and the pressure elongation. These contributions are decreased by the friction along the length of the buried pipe and by the passive pressure of the soil. If the

Input	Function	Display	Comments
			friction term is not considered, the equation is a simple linear statement. If the friction is considered, the equation becomes a quadratic equation. The smallest root is the one that is used. For each fitting (tee and elbow), the equation is solved. If the root of the quadratic is irrational, this indicates that a thrust block is not necessary. Also, if the delta value for either of the fittings is negative, this indicates that the buried pipe will be overstressed without a thrust block. The program then prints the values (or "UNLIMITED" or "OVERSTRESSED") and reinitializes.

Coding Form

Program Number HP-41CV-2 Title Thrust Blocks for Buried Pipe Fittings

Step/Line Key Entry	Key Code	Comments
01♦LBL "RTR"		Initializing routine. Clears Flags 1 and 2 and sets up the registers with the alpha names of the data for the input routine.
02 CF 01		
03 CF 02		
04 "OD"		
05 ASTO 01		
06 "WALL T"		
07 ASTO 02		
08 "El"		
09 ASTO 03		
10 "Ec"		
11 ASTO 04		
12 "ε"		
13 ASTO 05		
14 "PRESS"		
15 ASTO 06		
16 "KO"		
17 ASTO 07		
18 "Sa"		
19 ASTO 08		
20 "POISSN"		
21 ASTO 09		
22 "d.SOIL"		
23 ASTO 10		
24 "COVER"		
25 ASTO 11		
26 "FR.FAC"		
27 ASTO 12		
28 "d.PIPE"		
29 ASTO 13		
30 1.013		
31 STO 00		
32 FIX 3		
33♦LBL A		Input routine uses R00 as a pointer and a counter.
34 CLA		
35 SF 12		
36 ARCL IND 00		
37 "⊢="		
38 PROMPT		
39 ACA		
40 CF 12		
41 ACX		
42 STO IND 00		
43 PRBUF		
44 ISG 00		
45 GTO A		
46 ADV		Adjust units for El, Ec, and e.
47 CLA		
48 1 E6		
49 ST* 03		

Step/Line Key Entry	Key Code	Comments
50 ST* 04		
51 1200		
52 ST/ 05		
53 RCL 01		Calculate ID, store in R17.
54 RCL 02		
55 2		
56 *		
57 -		
58 STO 17		
59 X↑2		Calculate moment of inertia, store in R15.
60 X↑2		
61 RCL 01		
62 X↑2		
63 X↑2		
64 X<>Y		
65 -		
66 PI		
67 *		
68 64		
69 /		
70 STO 15		
71 PI		Calculate pipe cross-sectional area, store in R14.
72 RCL 02		
73 *		
74 RCL 01		
75 RCL 02		
76 -		
77 *		
78 STO 14		
79 RCL 07		Calculate λ, store in R16.
80 RCL 01		
81 *		
82 4		
83 /		
84 RCL 03		
85 /		
86 RCL 15		
87 /		
88 SQRT		
89 SQRT		
90 STO 16		
91 RCL 08		Maximum allowed thrust on a tee is calculated and stored in R18.
92 RCL 06		
93 RCL 17		
94 *		
95 2		
96 /		
97 RCL 02		
98 /		

Step/Line Key Entry	Key Code	Comments
99 RCL 03		
100 *		
101 RCL 04		
102 /		
103 RCL 09		
104 *		
105 RCL 05		
106 RCL 03		
107 *		
108 -		
109 ABS		
110 -		
111 8		
112 *		
113 RCL 16		
114 *		
115 RCL 15		
116 *		
117 RCL 01		
118 /		
119 STO 18		
120 RCL 08		Maximum allowed thrust on an elbow is calculated and stored in R19.
121 RCL 06		
122 RCL 17		
123 *		
124 4		
125 /		
126 RCL 02		
127 /		
128 -		
129 RCL 01		
130 4		
131 /		
132 RCL 15		
133 /		
134 RCL 16		
135 /		
136 RCL 14		
137 1/X		
138 -		
139 /		
140 STO 19		
141 RCL 10		Fill load on pipe is calculated and stored in R20. (2 We), #/in.
142 RCL 11		
143 *		
144 RCL 01		
145 *		
146 72		
147 /		

Step/ Line	Key Entry	Key Code	Comments
148	STO 20		
149	RCL 17		Weight of water is added to R20, #/in.
150	X↑2		
151	PI		
152	*		
153	111		
154	/		
155	ST+ 20		
156	RCL 01		Weight of pipe is added to R20, #/in.
157	X↑2		
158	RCL 17		
159	X↑2		
160	-		
161	PI		
162	*		
163	4		
164	/		
165	RCL 13		
166	*		
167	ST+ 20		
168	RCL 12		Friction Factor is Multiplied into R20.
169	ST* 20		
170	RCL 18		Maximum allowed deflection for a tee is calculated and stored in R22.
171	RCL 16		
172	*		
173	RCL 01		
174	/		
175	RCL 07		
176	/		
177	2		
178	/		
179	STO 22		
180	2		Maximum allowed deflection for an elbow is calculated and stored in R21.
181	*		
182	RCL 18		
183	/		
184	RCL 19		
185	*		
186	STO 21		
187	X<0?		For Δ ell and Δ tee less than zero, flags 1 and 2 are set, respectively.
188	SF 01		
189	RCL 22		
190	X<0?		
191	SF 02		
192	RCL 20		The friction term for the quadratic equation is calculated and stored in R23. This is A.
193	2		
194	/		
195	RCL 14		
196	/		
197	RCL 03		
198	/		
199	CHS		
200	STO 23		
201	RCL 19		The thrust term of the value B for tees is calculated and stored in R24.
202	RCL 14		
203	/		
204	RCL 03		
205	/		
206	CHS		
207	STO 24		
208	RCL 19		Thrust term for B is calculated for elbows and stored in R25.
209	/		
210	RCL 18		
211	*		
212	STO 25		
213	RCL 06		The pressure term is added to the thermal term for the value of B and is added to the registers 24 and 25.
214	RCL 17		
215	*		
216	4		
217	/		
218	RCL 02		
219	/		
220	RCL 03		
221	/		
222	1		
223	ENTER↑		
224	2		
225	ENTER↑		
226	RCL 09		
227	*		
228	RCL 03		
229	*		
230	RCL 04		
231	/		
232	-		
233	*		
234	RCL 05		
235	+		
236	ST+ 24		
237	ST+ 25		
238	24		Set pointers for quadratic equation.
239	STO 27		
240	21		
241	STO 26		
242	RCL 12		If the friction coefficient is zero, the safe length is a linear equation. Each Δ is divided by its B term. L ell is stored in R28, L tee in R29.
243	X≠0?		
244	GTO 10		
245	RCL 21		
246	RCL 24		
247	/		
248	STO 28		
249	RCL 22		
250	RCL 25		
251	/		
252	STO 29		
253	GTO D		
254	♦LBL 10		If friction is considered, the quadratic is solved for each value of L, for elbows and tees.
255	XEQ B		
256	STO 28		
257	1		
258	ST+ 26		
259	ST+ 27		
260	XEQ B		
261	STO 29		
262	♦LBL D		If Flag 1 is set, the piping is overstressed. A zero is stored in R28.
263	FC?C 01		
264	GTO 11		
265	0		
266	STO 28		
267	♦LBL 11		Same for Flag 2 and L tee.
268	FC?C 02		
269	GTO 12		
270	0		
271	STO 29		
272	♦LBL 12		"90° ELBOW" is printed.
273	SF 12		
274	FMT		
275	ACA		
276	57		
277	ACCHR		
278	48		
279	ACCHR		
280	34		
281	ACCHR		
282	" ELBOW"		
283	ACA		
284	PRBUF		
285	CLA		
286	ADV		
287	CF 12		If the value of L is not zero, the program jumps to label C.
288	RCL 28		
289	X≠0?		
290	GTO C		
291	XEQ 20		
292	GTO 18		
293	♦LBL C		If the value of L ell is equal to pi, this means an
294	PI		
295	X≠Y?		

Step/Line	Key Entry	Key Code	Comments
296	GTO E		unlimited length, hence no thrust block.
297	XEQ 21		
298	GTO 18		
299	♦LBL E		"SAFE L" is printed for elbows.
300	X<>Y		
301	12		
302	/		
303	"SAFE L="		
304	ACA		
305	ACX		
306	39		
307	ACCHR		
308	ADV		
309	ADV		
310	♦LBL 18		"TEE" is printed.
311	SF 12		
312	CLA		
313	FMT		
314	ACA		
315	"TEE"		
316	ACA		
317	PRBUF		
318	CLA		
319	ADV		
320	CF 12		
321	RCL 29		A zero value means the piping is overstressed.
322	X≠0?		
323	GTO C		
324	XEQ 20		
325	GTO 19		
326	♦LBL C		A π value of L means there is no need for a thrust block.
327	PI		
328	X≠Y?		
329	GTO E		
330	XEQ 21		
331	GTO 19		
332	♦LBL E		
333	X<>Y		
334	12		
335	/		
336	"SAFE L="		"SAFE L" for tees is printed.
337	ACA		
338	ACX		
339	39		
340	ACCHR		
341	ADV		
342	♦LBL 19		Return to initializer.
343	ADV		
344	ADV		
345	GTO "RTR"		
346	♦LBL 20		"OVER-STRESSED" is printed. (Thrust block required.)
347	"OVER"		
348	PRA		
349	CLA		
350	"STRESSED"		
351	PRA		
352	CLA		
353	ADV		
354	RTN		
355	♦LBL 21		"UNLIMITED" is printed. (No thrust block required.)
356	"UNLIMITED"		
357	PRA		
358	CLA		
359	ADV		
360	RTN		
361	♦LBL B		Solves quadratic equation. Calculates $B^2 - 4AC$ term.
362	RCL IND 27		
363	X↑2		
364	4		
365	RCL 23		
366	*		
367	RCL IND 26		
368	CHS		
369	*		
370	-		
371	X>0?		
372	GTO 30		
373	PI		If the term is < 0, return the value π.
374	RTN		
375	♦LBL 30		If the value of $B^2 - 4AC$ is positive, solve for L and return to main program.
376	SQRT		
377	RCL IND 27		
378	CHS		
379	+		
380	2		
381	/		
382	RCL 23		
383	/		
384	RTN		
385	.END.		

Chapter 3

First Natural Frequency for Three Distinct Piping Layouts

Program TI-59-3

Introduction:

TI-59-3 calculates the first natural frequency for three distinct piping layouts: two straight pipe spans with different end conditions and a two-member bend with 90- or 45-degree elbows. The source of the equation is *Design of Piping Systems* by the M. W. Kellogg Company. The analysis includes the weight of the pipe, the insulation, the fluid, and, in the case of the straight spans, a concentrated weight. The operating range is $0.25 \leq L1/L2 \leq 1.0$.

Nomenclature:

The amount of input varies, but there is a maximum of ten input items. They are:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- E: Cold modulus of elasticity (Mega psi)
- P: Concentrated weight (lb)
- FD: Fluid density (lb/ft^3)
- ID: Insulation density (lb/ft^3)
- IT: Insulation thickness (in)
- L1: For Case 1 and Case 2: The length between supports (ft)
  For Case 3: The shorter of the two lengths (ft)
- L2: For Case 1 and Case 2: Not applicable
  For Case 3: The longer of the two lengths (ft)
- ANGL: The angle of the elbow (90 or 45 degrees)

Four user-keys will be used to execute the program:

- A: Input
- B: Execute for Cases 1 and 2
- C: Execute for Case 3
- E: Initialize

Method:

The equations are derived from *Design of Piping Systems* by the M. W. Kellogg Company in the section of vibration control. They are as follows:

$$FN = \frac{1.18}{L^2}\sqrt{\frac{EI}{\frac{16P}{7L} + W}} \text{ (cps)} \qquad \text{For Case 1}$$

$$FN = \frac{1.70}{L^2}\sqrt{\frac{EI}{\frac{8P}{3L} + W}} \text{ (cps)} \qquad \text{For Case 2}$$

$$FN = \frac{\alpha}{L^2}\sqrt{\frac{EI}{W}} \text{ (cps)} \qquad \text{For Case 3}$$

VALUES OF α

L1/L2	0.25	0.50	0.75	1.00
ANGL = 90	1.62	1.48	1.33	1.18
ANGL = 45	1.64	1.58	1.50	1.39

Values of α

$L = L1 + L2$. For Cases 1 and 2, L2 is equal to zero.

where

FN = Natural frequency in cycles per second
E = Modulus of elasticity in psi
I = Pipe moment of inertia in in^3
W = Pipe weight per linear foot

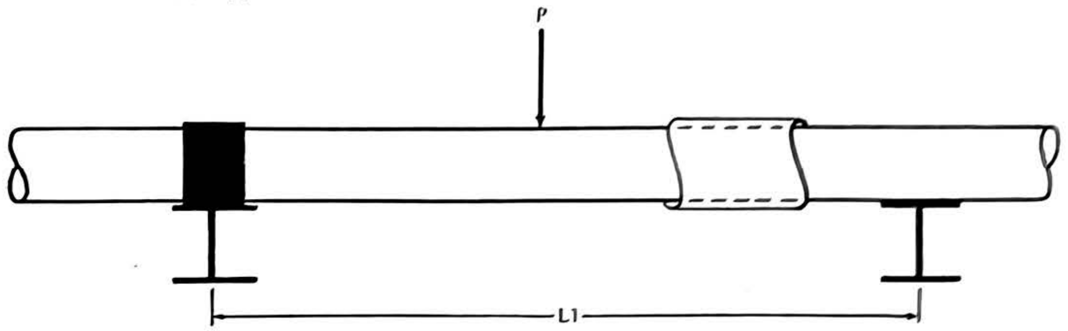
TI-59-3 interpolates between any two of the values of α in the chart, when doing the calculation for Case 3.

Limitations:

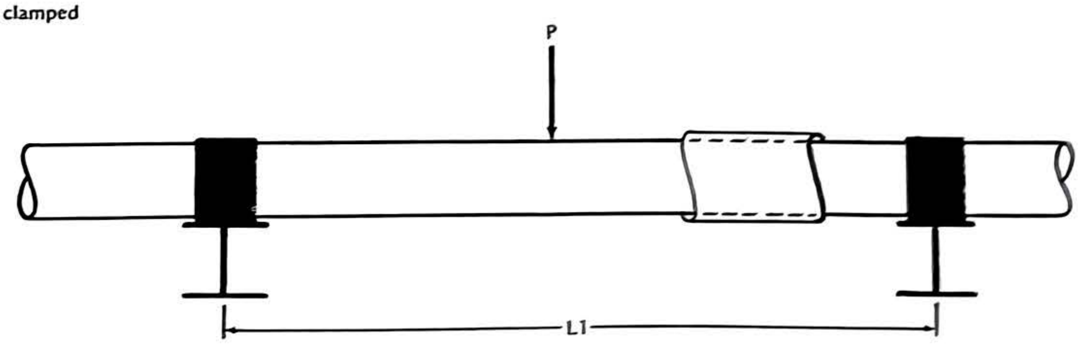
Because the program performs an interpolation between two values stored in memory, there are definite limits to the range that L1/L2 can have. If the program encounters a ratio outside the limits, it will print the message "OUT OF RANGE." The range is $0.25 \leq L1/L2 \leq 1.00$. TI-59-3 performs only one analysis per set of input data. It is self-initializing after the initial run. Once the user has run one analysis, the program initializes itself after printing the value of FN. The program does not interpolate for values of ANGL between 45 and 90 degrees. If ANGL is not 90 degrees, it assumes a value of 45. For Cases 1 and 2, P may be equal to zero.

Figure 3.1 First Natural Frequency of Three Pipe Layouts

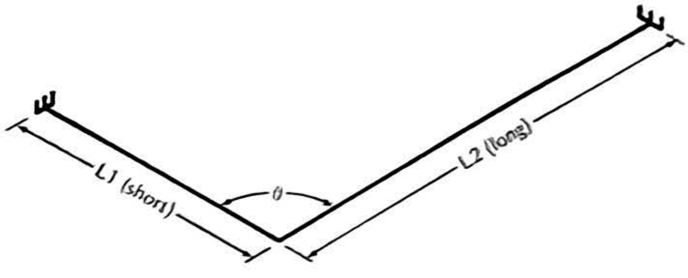
CASE 1:
One end clamped, one end simply supported



CASE 2:
Both ends clamped



CASE 3:
Two-member layout, both ends clamped, vibration perpendicular to layout
θ may be 90° (a 90° elbow) or 135° (a 45° elbow)



User Instructions

Program Number TI-59-3 **Title** First Natural Frequency

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards (3 sides total).		CLR	1, 2, or 3
2	Initialize program.		E	0
3	Input OD.	OD	A	OD
4	Input T.	T	A	T
5	Input E.	E	A	E
6	Input P.	P	A	P
7	Input FD.	FD	A	FD
8	Input ID.	ID	A	ID
9	Input IT.	IT	A	IT
10	Input L1.	L1	A	L1
11	Input L2*.	L2	A	L2
12	Input ANGL*.	ANGL	A	ANGL
13	Choose analysis desired.			
	CASES 1 and 2		B	
	CASE 3		C	
				FN

*These steps are necessary for Case 3 only.

Data Register Contents

REGI-STER	DATA	REGI-STER	DATA		
00	POINTER	30	1.18		
01	OD	31	1.62		
02	T	32	1.48		
03	E	33	1.33		
04	P	34	1.64	values of α	
05	FD	35	1.58		
06	ID	36	1.50		
07	IT	37	1.39		
08	L1	38			
09	L2	39			
10	ANGL	40			
11	PIPE MOMENT OF INERTIA	41			
12	WPI pipe/total WPI	42			
13	WPI insul.	43			
14	WPI fluid	44	2702632703	"L1/L2"	
15	L (L1 + L2)	45	3241	"OU"	
16	FN (1&3)	46	3700322100	"T OF "	
17	FN (2)	47	3513312217	"RANGE"	
18	EI	48	1513361701	"CASEO"	
19		49	POINTER		
20	POINTER	50	3216	"OD"	
21	POINTER	51	37	"T"	
22		52	17	"E"	alpha labels
23	L1/L2	53	33	"P"	
24		54	2116	"FD"	
25	α	55	2416	"ID"	
26		56	2437	"IT"	
27		57	2702	"L1"	
28		58	2703	"L2"	
29		59	13312227	"ANGL"	

```
12.75     OD
0.375      T
27.9       E
350.       P
62.4      FD
11.       ID
4.5       IT
15.       L1

CASE1
35.46     FN

CASE2
49.80     FN
```

```
12.75     OD
0.375      T
27.9       E
0.         P
62.4      FD
11.       ID
4.5       IT
5.        L1
16.       L2
90.     ANGL

CASE3
L1/L2
0.31
29.32     FN
```

```
12.75     OD
0.375      T
27.9       E
0.         P
62.4      FD
11.       ID
4.5       IT
5.        L1
16.       L2
45.     ANGL

CASE3
L1/L2
0.31
30.06     FN
```

Examples of data that are outside of the range of the data stored in memory.

```
12.75     OD
0.375      T
27.9       E
0.         P
62.4      FD
11.       ID
4.5       IT
3.        L1
16.       L2
90.     ANGL

CASE3
L1/L2
0.19

OUT OF RANGE
```

```
12.75     OD
0.375      T
27.9       E
0.         P
62.4      FD
11.       ID
4.5       IT
20.       L1
19.       L2
45.     ANGL

CASE3
L1/L2
1.05

OUT OF RANGE
```

Natural Frequency

OD = 12.75″	FD = 62.4 #/ft^3
T = 0.375″	ID = 11 #/ft^3
E = 27900000 psi	IT = 4.5″
P = 350 #	

CASES I AND II

L1 = 15′
(12.75 − .375)(.375)(PI)(12)(.283) = 49.510 #/ft pipe weight
(12.75 − 2(.375))^2(PI)/576 × 62.4 =49.009 #/ft water weight
((12.75 + 2(4.5))^2 − (12.75)^2)(PI)/576 × 11 = 18.629 #/ft insulation weight

Total Weight = 117.148 #/ft
(12.75^4 − 12^4)(PI)/64 = 279.335 in^4 Pipe moment of inertia

$$\frac{(1.18)}{(15)^2} \times \sqrt{\frac{(27.9EE6)(279.335)}{\frac{(16)(350)}{(7)(15)} + 117.148}} = 35.459 \text{ cps}$$

$$\frac{(1.70)}{(15)^2} \times \sqrt{\frac{(27.9EE6)(279.335)}{\frac{(8)(350)}{(3)(15)} + 117.148}} = 49.803 \text{ cps}$$

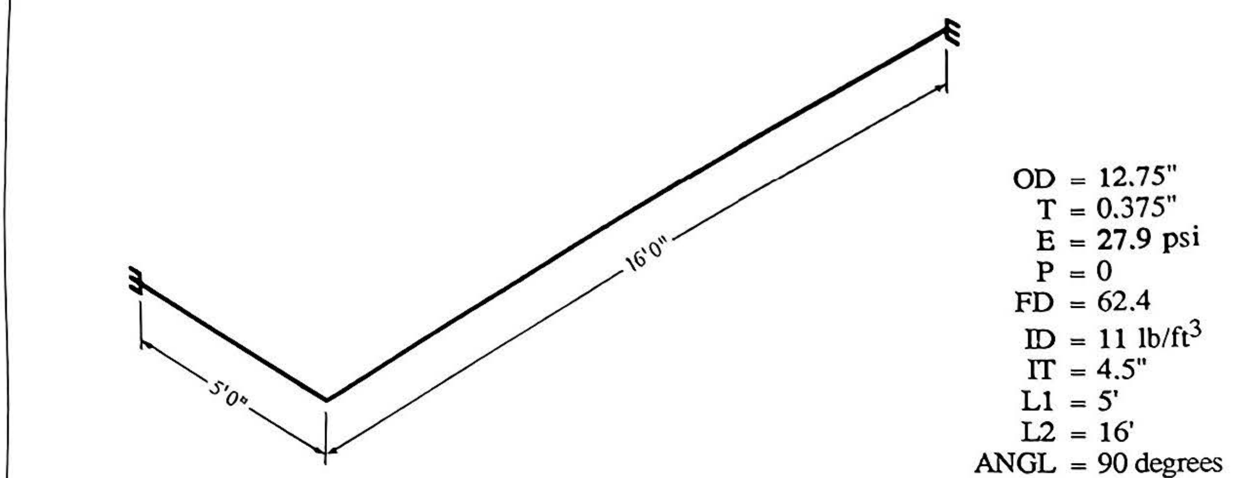
CASE III

L1 = 5′; L2 = 16′
L1/L2 = 5/16 = 0.313
For 90° α = 1.62 @ L1/L2 = 0.25
α = 1.48 @ L1/L2 = 0.50
Interpolate for α @ L1/L2 = 0.313 ∴ α = 1.585

$$\frac{(1.585)}{(16 + 5)} + \sqrt{\frac{(27.9EE6)(279.335)}{(117.148)}} = 29.315 \text{ cps}$$

Sample Problem

Program: TI-59-3



Step	Input	Key Stroke	Display	Printer		Comments
1		E	0			Initializes program. Zeros out key registers, sets the pointer for the input routine.
2	12.75	A	12.75	12.75	OD	Input step. Program stores OD in R01 and then prints the value and its alpha label.
3	.375	A	0.375	0.375	T	Store T in R02, print.
4	27.9	A	27.9	27.9	E	Store E in R03, print.
5	0	A	0.	0.	P	Store P in R04, print.
6	62.4	A	62.4	62.4	FD	Store FD in R05, print.
7	11	A	11.	11.	ID	Store ID in R06, print.
8	4.5	A	4.5	4.5	IT	Store IT in R07, print.
9	5	A	5.	5.	L1	Store L1 in R08, print.
10	16	A	16.	16.	L2	Store L2 in R09, print.
11	90	A	90.	90.	ANGL	Store ANGL in R10, print.
12		C	0.			
				CASE3		
				L1/L2		
				0.31		
				29.32	FN	Program executes the calculations for Case 3, prints the value of L1/L2, and then prints the value of FN in cps. After printing the natural frequency, the program performs the initializing automatically.

Coding Form

Program Number TI-59-3 **Title** First Natural Frequency

Loc	Code	Key	Comments	Loc	Code	Key	Comments	Loc	Code	Key	Comments
000	76	LBL	Input routine uses	060	06	6		120	42	STO	
001	11	A	R00 and R49 as	061	95	=		121	23	23	
002	32	X:T	pointers.	062	49	PRD		122	25	CLR	
003	01	1		063	11	11		123	98	ADV	
004	44	SUM		064	43	RCL		124	43	RCL	
005	49	49		065	01	01		125	48	48	
006	69	OP		066	85	+		126	85	+	
007	20	20		067	02	2		127	43	RCL	
008	73	RC*		068	65	×		128	22	22	
009	49	49		069	43	RCL		129	95	=	
010	69	OP		070	07	07		130	69	OP	
011	04	04		071	54	)		131	00	00	
012	32	X:T		072	33	X^2		132	69	OP	
013	69	OP		073	65	×		133	02	02	CASE # is printed.
014	06	06		074	89	π		134	69	OP	
015	72	ST*		075	55	÷		135	05	05	
016	00	00		076	04	4		136	69	OP	
017	91	R/S		077	75	-		137	00	00	
018	76	LBL	Subroutine:	078	43	RCL		138	43	RCL	
019	17	B'		079	14	14		139	08	08	
020	43	RCL	Calculates Pipe	080	95	=		140	85	+	Total L ($L_1 + L_2$) is
021	01	01	Moment of Inertia,	081	42	STO		141	43	RCL	stored in R15.
022	33	X^2	Weight per foot	082	14	14		142	09	09	
023	42	STO	(WPF) of pipe,	083	01	1		143	95	=	
024	12	12	fluid, and	084	04	4		144	42	STO	
025	42	STO	insulation.	085	04	4		145	15	15	
026	14	14		086	35	1/X		146	92	RTN	
027	33	X^2		087	49	PRD		147	76	LBL	Natural frequency
028	42	STO		088	12	12		148	16	A'	subroutine.
029	11	11		089	49	PRD		149	55	÷	
030	43	RCL	Pipe WPF is in R12.	090	13	13		150	43	RCL	
031	01	01		091	49	PRD		151	15	15	
032	75	-		092	14	14		152	33	X^2	
033	02	2	Fluid WPF is in	093	04	4		153	35	1/X	α is supplied by
034	65	×	R13.	094	08	8		154	42	STO	the main routine.
035	43	RCL		095	09	9		155	17	17	
036	02	02	Insulation WPF is	096	49	PRD		156	35	1/X	
037	54	)	in R14.	097	12	12		157	95	=	
038	33	X^2		098	43	RCL		158	42	STO	
039	42	STO		099	06	06		159	16	16	
040	13	13		100	49	PRD		160	01	1	
041	94	+/-	Moment of inertia	101	14	14		161	93	.	
042	44	SUM	is in R11.	102	43	RCL	Fluid WPF and	162	07	7	
043	12	12		103	05	05	Insulation WPF are	163	49	PRD	
044	33	X^2		104	49	PRD	summed into R12 for	164	17	17	
045	94	+/-		105	13	13	a Total WPF.	165	43	RCL	
046	44	SUM		106	43	RCL		166	11	11	
047	11	11		107	13	13		167	65	×	
048	89	π		108	85	+		168	43	RCL	
049	55	÷		109	43	RCL		169	03	03	
050	04	4		110	14	14		170	52	EE	
051	95	=		111	95	=		171	06	6	
052	49	PRD		112	44	SUM		172	22	INV	
053	12	12		113	12	12		173	52	EE	
054	49	PRD		114	43	RCL		174	95	=	
055	13	13		115	08	08		175	42	STO	
056	49	PRD		116	55	÷	L1/L2 ratio is stored	176	18	18	
057	14	14		117	43	RCL	in R23.	177	55	÷	
058	55	÷		118	09	09		178	53	(	
059	01	1		119	95	=		179	01	1	

Loc	Code	Key	Comments	Loc	Code	Key	Comments	Loc	Code	Key	Comments
180	06	6		240	43	RCL		300	22	22	
181	65	×		241	23	23		301	00	0	
182	43	RCL		242	95	=		302	42	STO	
183	04	04		243	59	INT		303	09	09	
184	55	÷		244	85	+		304	17	B'	
185	07	7		245	43	RCL	This is used for Case 3 only.	305	43	RCL	
186	55	÷	FN for Cases 1 and 3 is stored in R16.	246	19	19		306	30	30	
187	43	RCL		247	85	+		307	16	A'	
188	15	15		248	03	3		308	43	RCL	
189	85	+		249	00	0		309	48	48	
190	43	RCL		250	95	=		310	85	+	"CASE 2" is printed.
191	12	12		251	42	STO		311	02	2	
192	54	)		252	20	20		312	95	=	
193	95	=	FN for Case 2 is stored in R17.	253	85	+		313	69	OP	
194	34	√x		254	01	1		314	00	00	
195	49	PRD		255	95	=		315	69	OP	
196	16	16		256	42	STO		316	02	02	
197	43	RCL		257	21	21		317	69	OP	
198	18	18		258	73	RC*		318	05	05	
199	55	÷		259	20	20		319	69	OP	
200	53	(		260	75	−		320	00	00	
201	08	8		261	53	(		321	02	2	
202	65	×		262	43	RCL		322	01	1	FN for Case 2 is printed.
203	43	RCL		263	23	23		323	03	3	
204	04	04		264	75	−		324	01	1	
205	55	÷		265	53	(		325	69	OP	
206	03	3		266	43	RCL		326	04	04	
207	55	÷		267	20	20		327	43	RCL	
208	43	RCL		268	75	−		328	17	17	
209	15	15		269	03	3		329	58	FIX	
210	85	+		270	00	0		330	02	02	
211	43	RCL		271	75	−		331	69	OP	
212	12	12		272	43	RCL		332	06	06	
213	54	)		273	19	19		333	22	INV	
214	95	=		274	54	)		334	58	FIX	
215	34	√x		275	65	×		335	98	ADV	
216	49	PRD		276	93	.		336	15	E	Initialize.
217	17	17		277	02	2		337	76	LBL	Main Control for Case 3.
218	02	2		278	05	5		338	13	C	
219	01	1	FN is printed for Cases 1 and 3.	279	54	)		339	03	3	
220	03	3		280	55	÷		340	42	STO	
221	01	1		281	93	.		341	22	22	
222	69	OP		282	02	2		342	17	B'	
223	04	04		283	05	5		343	43	RCL	
224	43	RCL		284	65	×		344	44	44	
225	16	16		285	53	(		345	69	OP	
226	58	FIX		286	73	RC*		346	00	00	L1/L2 is printed.
227	02	02		287	20	20		347	69	OP	
228	69	OP		288	75	−		348	01	01	
229	06	06		289	73	RC*		349	69	OP	
230	22	INV		290	21	21		350	05	05	
231	58	FIX		291	54	)	α is stored in R25.	351	69	OP	
232	98	ADV		292	95	=		352	00	00	
233	92	RTN		293	42	STO		353	43	RCL	
234	76	LBL	Subroutine: α is calculated by interpolation from data in memory.	294	25	25		354	23	23	
235	18	C'		295	92	RTN		355	58	FIX	
236	42	STO		296	76	LBL	Main control for Cases 1 and 2.	356	02	02	
237	19	19		297	12	B		357	99	PRT	
238	04	4		298	01	1		358	22	INV	
239	65	×		299	42	STO		359	58	FIX	

Loc	Code	Key	Comments
360	29	CP	
361	43	RCL	Program tests L1/L2 to see if it falls outside the allowed range.
362	23	23	
363	75	-	
364	93	.	
365	02	2	
366	05	5	
367	95	=	
368	22	INV	
369	77	GE	
370	47	CMS	
371	01	1	
372	75	-	
373	43	RCL	
374	23	23	
375	95	=	
376	22	INV	
377	77	GE	
378	47	CMS	
379	09	9	If ANGL is not 90°, go to LOG.
380	00	0	
381	32	X:T	
382	43	RCL	
383	10	10	
384	67	EQ	
385	28	LOG	
386	04	4	
387	61	GTO	
388	23	LNX	
389	76	LBL	
390	28	LOG	
391	00	0	
392	76	LBL	
393	23	LNX	
394	18	C'	
395	16	A'	
396	15	E	Initialize.
397	76	LBL	Program initializer.
398	15	E	
399	00	0	
400	42	STO	
401	04	04	
402	42	STO	
403	05	05	
404	42	STO	
405	06	06	
406	42	STO	
407	07	07	
408	42	STO	
409	08	08	
410	42	STO	
411	09	09	
412	42	STO	
413	00	00	
414	04	4	
415	09	9	
416	42	STO	
417	49	49	
418	25	CLR	
419	91	R/S	

Loc	Code	Key	Comments
420	76	LBL	Print routine for values of L1/L2 that are out of range.
421	47	CMS	
422	43	RCL	
423	45	45	
424	69	OP	
425	02	02	
426	43	RCL	
427	46	46	
428	69	OP	
429	03	03	
430	43	RCL	
431	47	47	
432	69	OP	
433	04	04	
434	98	ADV	
435	69	OP	
436	05	05	
437	98	ADV	
438	25	CLR	
439	15	E	

The following data must be stored in memory and then recorded onto a magnetic card (side 3).

1.18	30
1.62	31
1.48	32
1.33	33
1.18	34
1.64	35
1.58	36
1.5	37
1.39	38
0.	39
0.	40
0.	41
0.	42
0.	43
2702632703.	44
3241.	45
3700322100.	46
3513312217.	47
1513361701.	48
0.	49
3216.	50
37.	51
17.	52
33.	53
2116.	54
2416.	55
2437.	56
2702.	57
2703.	58
13312227.	59

Loc	Code	Key	Comments

Natural Frequency Calculations

Cases 1 & 2

Pipe outside diameter (in)
Pipe wall thickness (in)
Cold modulus of elasticity (psi)
P [concentrated weight (lbs)]
Fluid density (lb/ft^3)
Insulation density (lb/ft^3)
Insulation thickness (in)
Length of span (ft)

Natural frequency (cps)

Natural frequency (cps)

Case 3

Pipe outside diameter (in)
Pipe wall thickness (in)
Cold modulus of elasticity (psi)
P [concentrated weight (lbs)]
Insulation density (lb/ft^3)
Insulation thickness (in)
Shorter of the two pipe lengths (ft)
Longer of the two pipe lengths (ft)
Elbow angle (90 or 45)

Ratio of short leg to long leg

Natural frequency (cps)

Program HP-41CV-3: First Natural Frequency for Three Distinct Piping Layouts

Introduction:

HP-41CV-3 calculates the first natural frequency for three distinct piping layouts: two straight pipe spans with different end conditions and a two member bend with 90- or 45-degree elbows. The source of the equations is *Design of Piping Systems* by the M. W. Kellogg Company. The analysis includes the weight of the pipe, the insulation, the fluid, and, in the case of the straight spans, a concentrated weight. The operating range is $0.25 \leq L1/L2 \leq 1.0$.

Nomenclature:

The amount of input varies, but there is a maximum of ten input items. They are:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- E: Cold modulus of elasticity (Mega psi)
- P: Concentrated weight (lb)
- FD: Fluid density (lb/ft^3)
- ID: Insulation density (lb/ft^3)
- IT: Insulation thickness (in)
- L1: For Case 1 and Case 2: The length between supports (ft)
  For Case 3: The shorter of the two lengths (ft)
- L2: For Case 1 and Case 2: Not applicable
  For Case 3: The longer of the two lengths (ft)
- ANGL: The angle of the elbow (90 or 45 degrees)

Three user-keys will be used to execute the program.

- A: Execute for Cases 1 and 2
- B: Execute for Case 3
- E: Initialize

Method:

The equations are derived from *Design of Piping Systems* by the M. W. Kellogg Company in the section on vibration control. They are as follows:

$$FN = \frac{1.18}{L^2}\sqrt{\frac{EI}{\frac{16P}{7L} + W}} \text{ (cps)} \qquad \text{For Case 1}$$

$$FN = \frac{1.70}{L^2}\sqrt{\frac{EI}{\frac{8P}{3L} + W}} \text{ (cps)} \qquad \text{For Case 2}$$

$$FN = \frac{\alpha}{L^2}\sqrt{\frac{EI}{W}} \text{ (cps)} \qquad \text{For Case 3}$$

VALUES OF α

L1/L2	0.25	0.50	0.75	1.00
ANGL = 90	1.62	1.48	1.33	1.18
ANGL = 45	1.64	1.58	1.50	1.39

Values of α

$L = L1 + L2$. For Cases 1 and 2, L2 is equal to zero.

HP-41CV-3 interpolates between any two of the values of in the chart, when doing the calculation for Case 3.

where

FN = Natural frequency in cycles per second
E = Modulus of elasticity in psi
I = Moment of inertia in in^3
W = Pipe weight per linear foot

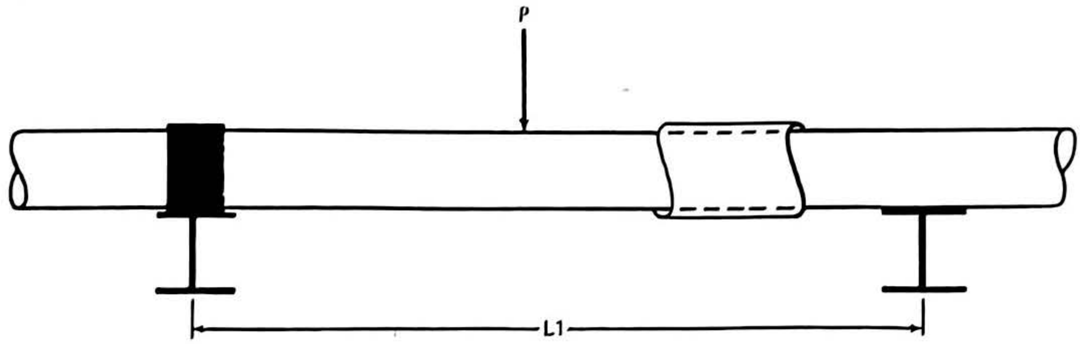
Limitations:

Because the program performs an interpolation between two values stored in memory, there are definite limits to the range that L1/L2 can have. If the program encounters a ratio outside the limits, it will print the message "OUT OF RANGE." The range of $0.25 \leq L1/L2 \leq 1.00$. HP-41CV-3 performs only one analysis per set of input data. It is self-initializing after the initial run. Once the user has run one analysis, the program initializes itself after printing the value of FN. The program does not interpolate for values of ANGL between 45 and 90 degrees. If ANGL is not 90 degrees, it assumes a value of 45.

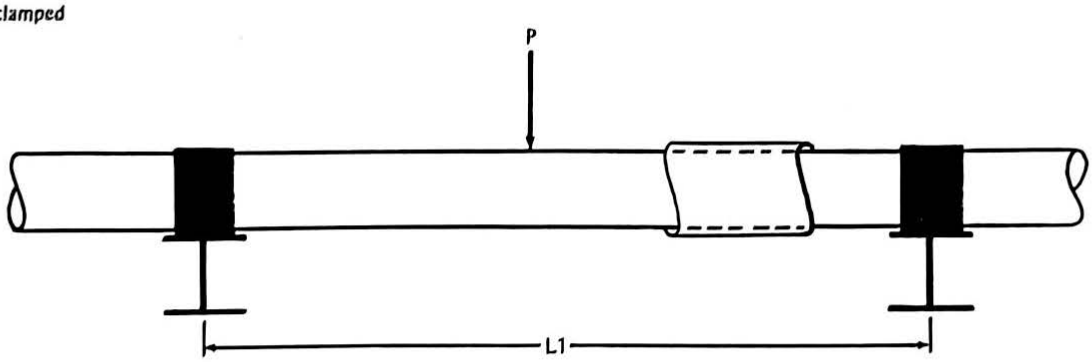
For Cases 1 and 2, P may be equal to zero.

Figure 3.2 First Natural Frequency for Three Piping Layouts

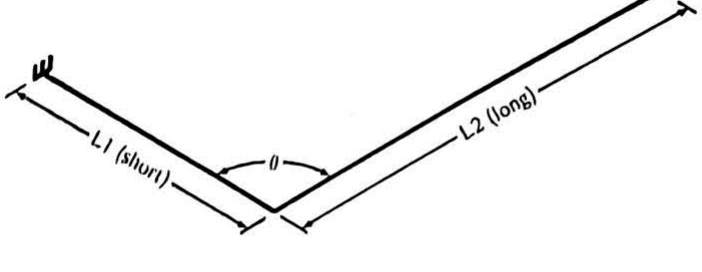
CASE 1:
One end clamped, one end simply supported



CASE 2:
Both ends clamped

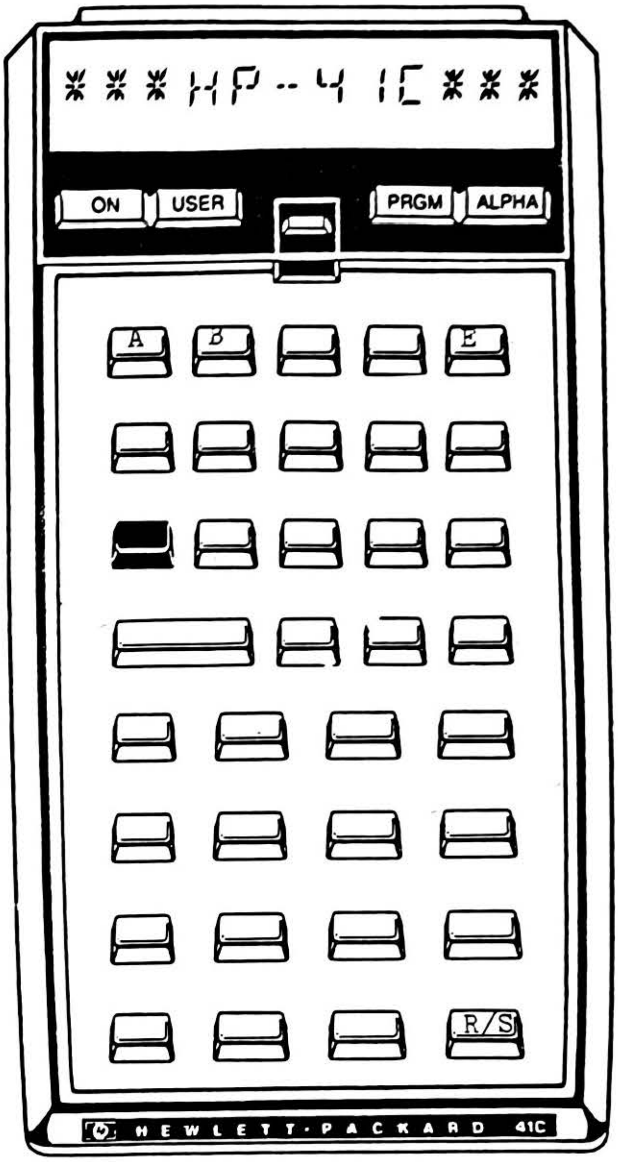


CASE 3:
Two-member layout, both ends clamped, vibration perpendicular to layout
θ may be 90° (a 90° elbow) or 135° (a 45° elbow)

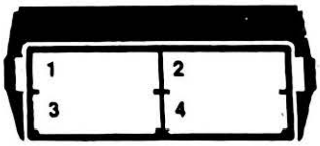


Keyboard Card Labeling

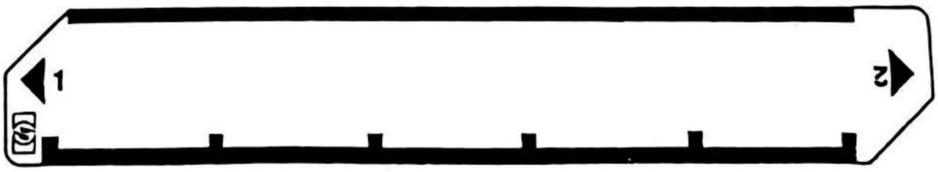
KEYBOARD



SYSTEM
CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-3 **Title** First Natural Frequency

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards (6 sides).			
2	Initialize program.		E	A OR B
3	Choose which case to be analyzed.		A or B	OD=
4	Input OD.	OD	R/S	T=
5	Input T.	T	R/S	E=
6	Input E.	E	R/S	P=
7	Input P.	P	R/S	FD=
8	Input FD.	FD	R/S	ID=
9	Input ID.	ID	R/S	IT=
10	Input IT.	IT	R/S	L1=
11	Input L1.	L1	R/S	
	If Cases 1 and 2 are chosen, the program will shift to the analysis. If Case 3 is chosen:			L2=
12	Input L2.	L2	R/S	ANGL=
13	Input ANGL.	ANGL	R/S	output

Registers, Flags, Assignments

Program Number HP-41CV-3 **Title** First Natural Frequency

DATA REGISTERS

00	IND
01	OD
02	T
03	E
04	P
05	FD
06	ID
07	IT
08	L1
09	L2
10	ANGL
11	Pipe moment of inertia
12	WPF pipe/Total WPF
13	WPF fluid
14	WPF insulation
15	L total
16	FN for Cases 1 and 3
17	FN for Case 2
18	EI
19	alpha
20	IND
21	IND
22	
23	L1/L2
24	
25	1.18
26	1.62
27	1.48
28	1.33
29	1.18
30	1.64
31	1.58
32	1.50
33	1.39
34	
35	
36	
37	
38	
39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates
1	C	Cases 1 and 2	Case 3

ASSIGNMENTS

Label	Key	Function	Key
AB	11 (A)		
AC	12 (B)		
FN	15 (E)		

Examples of data that are outside of the range of the data stored in memory.

```
OD= 12.750
T= 0.375
E= 27.900
P= 350.000
FD= 62.400
ID= 11.000
IT= 4.500
L1= 15.000

CASE 1
        FN= 35.46

CASE 2

        FN= 49.80
```

```
OD= 12.750
T= 0.375
E= 27.900
P= 0.000
FD= 62.400
ID= 11.000
IT= 4.500
L1= 5.000
L2= 16.000
ANGL= 90.000

L1/L2= 0.313

CASE 3

        FN= 29.32
```

```
OD= 12.750
T= 0.375
E= 27.900
P= 0.000
FD= 62.400
ID= 11.000
IT= 4.500
L1= 5.000
L2= 16.000
ANGL= 45.000

L1/L2= 0.313

CASE 3

        FN= 30.05
```

```
OD= 12.750
T= 0.375
E= 27.900
P= 0.000
FD= 62.400
ID= 11.000
IT= 4.500
L1= 3.000
L2= 16.000
ANGL= 90.000

L1/L2= 0.188

OUT OF RANGE
```

```
OD= 12.750
T= 0.375
E= 27.900
P= 0.000
FD= 62.400
ID= 11.000
IT= 4.500
L1= 20.000
L2= 19.000
ANGL= 45.000

L1/L2= 1.053

OUT OF RANGE
```

$$OD = 12.75'' \qquad FD = 62.4\ \#/ft^3$$
$$T = 0.375'' \qquad ID = 11\ \#/ft^3$$
$$E = 27900000\ psi \qquad IT = 4.5''$$
$$P = 350\ \#$$

CASES I AND II

L1 = 15′
(12.75 − .375)(.375)(PI)(12)(.283) = 49.510 #/ft pipe weight
$(12.75 - 2(.375))^2$(PI)/576 × 62.4 =49.009 #/ft water weight
$((12.75 + 2(4.5))^2 - (12.75)^2)$(PI)/576 × 11 = 18.629 #/ft insulation weight

Total Weight = 117.148 #/ft
$(12.75^4 - 12^4)$(PI)/64 = 279.335 in^4 Pipe moment of inertia

$$\frac{(1.18)}{(15)^2} \times \sqrt{\frac{(27.9EE6)(279.335)}{\frac{(16)(350)}{(7)(15)} + 117.148}} = 35.459 \text{ cps}$$

$$\frac{(1.70)}{(15)^2} \times \sqrt{\frac{(27.9EE6)(279.335)}{\frac{(8)(350)}{(3)(15)} + 117.148}} = 49.803 \text{ cps}$$

CASE III

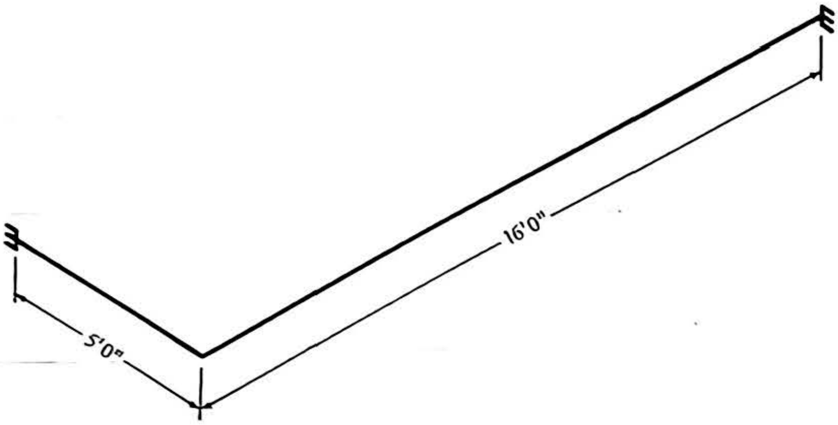
L1 = 5′; L2 = 16′
L1/L2 = 5/16 = 0.313
For 90° $\alpha = 1.62$ @ L1/L2 = 0.25
$\alpha = 1.48$ @ L1/L2 = 0.50
Interpolate for α @ L1/L2 = 0.313 ∴ $\alpha = 1.585$

$$\frac{(1.585)}{(16 + 5)} + \sqrt{\frac{(27.9EE6)(279.335)}{(117.148)}} = 29.315 \text{ cps}$$

Sample Problem

Program: HP-41CV-3 Title First Natural Frequency

Sample Problem (Sketch if Desired)



OD = 12.75"
T = 0.275"
E = 27.9EE6 psi
P = 0
FD = 62.4 lb/ft^3
ID = 11 lb/ft^3
IT = 4.5"
L1 = 5'
L2 = 16'
ANGL = 90 degrees

Input	Function	Display	Comments
	E	A OR B	Initialize program; prompts for analysis case.
	B	OD=	Choose Case 3; prompts for OD
12.75	R/S	T=	Input OD; prompts for T.
0.375	R/S	E=	Input T; prompts for E.
27.9	R/S	P=	Input E; prompts for P.
0.0	R/S	FD=	Input P; prompts for FD.
62.4	R/S	ID=	Input FD; prompts for ID.
11.0	R/S	IT=	Input ID; prompts for IT.
4.5	R/S	L1=	Input IT; prompts for L1.
5.0	R/S	L2=	Input L1; prompts for L2.
16.0	R/S	ANGL=	Input L2; prompts for ANGL.
90	R/S		Input ANGL; program shifts to analysis.
		L1/L2= 0.313	
		CASE 3	
		FN= 29.32	

Coding Form

Program Number HP-41CV-3 **Title** First Natural Frequency

Step/Line	Key Entry	Key Code	Comments
01	♦LBL "NF"		Initializing routine stores alpha labels and values for α.
02	CF 01		
03	CLRG		
04	"OD="		
05	ASTO 01		
06	"T="		
07	ASTO 02		
08	"E="		
09	ASTO 03		
10	"P="		Sets pointer R_{00} for input routine.
11	ASTO 04		
12	"FD="		
13	ASTO 05		
14	"ID="		
15	ASTO 06		
16	"IT="		
17	ASTO 07		
18	"L1="		
19	ASTO 08		
20	"L2="		
21	ASTO 09		
22	"ANGL="		
23	ASTO 10		
24	1.18		
25	STO 30		
26	STO 34		
27	1.62		
28	STO 31		
29	1.48		
30	STO 32		
31	1.33		
32	STO 33		
33	1.64		
34	STO 35		
35	1.58		
36	STO 36		
37	1.5		
38	STO 37		
39	1.39		
40	STO 38		
41	1		
42	STO 00		
43	"A OR B"		Prompts user for analysis.
44	PROMPT		
45	♦LBL "AB"		Case 1 and Case 2 main control.
46	CLA		
47	8		
48	STO 11		
49	SF 01		

Step/Line	Key Entry	Key Code	Comments
50	XEQ 10		Sets counter R_{11}, sets R_{09} to zero, calls all subroutines.
51	0		
52	STO 09		
53	XEQ B		
54	RCL 30		
55	XEQ A		
56	ADV		
57	ADV		
58	GTO "NF"		
59	♦LBL "AC"		Case 3 main control sets pointer R_{11}, goes to input routine.
60	CLA		
61	10		
62	STO 11		
63	XEQ 10		
64	XEQ B		
65	ADV		
66	"L1/L2="		Prints value of L1/L2.
67	SF 12		
68	ACA		
69	CF 12		
70	RCL 23		
71	ACX		
72	PRBUF		
73	CLA		Tests to see if L1/L2 is within the range of the analysis.
74	ADV		
75	.25		
76	X>Y?		
77	GTO 20		
78	CLX		
79	1		
80	X<>Y		
81	X>Y?		
82	GTO 20		
83	90		Tests ANGL to see if it is equal to 90.
84	RCL 10		
85	X=Y?		
86	GTO 30		
87	4		
88	GTO 35		
89	♦LBL 30		
90	0		
91	♦LBL 35		
92	STO 19		
93	RCL 23		
94	4		
95	*		
96	INT		
97	RCL 19		
98	+		

Step/Line	Key Entry	Key Code	Comments
99	30		Sets pointers R20 and R21 for interpolation routine.
100	+		
101	STO 20		
102	1		
103	+		
104	STO 21		
105	RCL 23		Interpolation routine: Finds value of α from between two values in memory.
106	RCL 20		
107	30		
108	-		
109	RCL 19		
110	-		
111	.25		
112	*		
113	-		
114	.25		
115	/		
116	RCL IND 20		
117	RCL IND 21		
118	-		
119	*		
120	RCL IND 20		
121	X<>Y		
122	-		
123	XEQ A		Executes natural frequency routine and initializes.
124	ADV		
125	ADV		
126	GTO "NF"		
127	♦LBL 10		Input routine. Uses R00 as a pointer and R11 as a counter.
128	FIX 3		
129	SF 12		
130	CLA		
131	ARCL IND 00		
132	PROMPT		
133	ACA		
134	CF 12		
135	ACX		
136	STO IND 00		
137	PRBUF		
138	1		
139	ST+ 00		
140	CLX		
141	DSE 11		
142	GTO 10		
143	RTN		
144	♦LBL B		Calculates pipe moment of inertia, pipe weight-per-foot (WPF),
145	RCL 01		
146	X↑2		
147	STO 12		

Step/ Line	Key Entry	Key Code	Comments
148	STO 14		insulation WPF, and fluid WPF. Pipe WPF is in R12. Insulation WPF is in R14. Fluid WPF is in R13. Moment of Inertia is in R11.
149	X↑2		
150	STO 11		
151	RCL 01		
152	RCL 02		
153	2		
154	*		
155	-		
156	X↑2		
157	STO 13		
158	ST- 12		
159	X↑2		
160	ST- 11		
161	PI		
162	4		
163	/		
164	ST* 12		
165	ST* 13		
166	ST* 14		
167	16		
168	/		
169	ST* 11		
170	RCL 01		
171	RCL 07		
172	2		
173	*		
174	+		
175	X↑2		
176	PI		
177	*		
178	4		
179	/		
180	RCL 14		
181	-		
182	STO 14		
183	144		Change weight per inch to weight-per-foot.
184	ST/ 12		
185	ST/ 13		
186	ST/ 14		
187	489		Steel pipe factor.
188	ST* 12		
189	RCL 06		Complete WPF calculations.
190	ST* 14		
191	RCL 05		
192	ST* 13		
193	RCL 13		Sum all WPFs into R12 for a total WPF.
194	RCL 14		
195	+		
196	ST+ 12		

Step/ Line	Key Entry	Key Code	Comments
197	RCL 08		If Cases 1 and 2 go to 11.
198	FS? 01		
199	GTO 11		
200	RCL 08		Calculate L1/L2.
201	RCL 09		
202	/		
203	STO 23		
204	♦LBL 11		L is the total of L1 + L2. For cases 1 and 2 L2 = 0.
205	RCL 08		
206	RCL 09		
207	+		
208	STO 15		
209	RTN		
210	♦LBL A		Natural frequency routine:
211	STO 40		
212	RCL 15		
213	X↑2		
214	/		
215	STO 16		FN for Cases 1 and 3 is in R16. FN for Case 2 is in R17. EI is in R18.
216	1.7		
217	RCL 15		
218	X↑2		
219	/		
220	STO 17		
221	RCL 11		
222	RCL 03		
223	*		
224	1 E6		
225	*		
226	STO 18		
227	16		
228	RCL 04		
229	*		
230	7		
231	/		
232	RCL 15		
233	/		
234	RCL 12		
235	+		
236	/		
237	SQRT		
238	ST* 16		
239	RCL 18		
240	8		
241	RCL 04		
242	*		
243	3		
244	/		
245	RCL 15		

Step/ Line	Key Entry	Key Code	Comments
246	/		
247	RCL 12		
248	+		
249	/		
250	SQRT		
251	ST* 17		
252	FC? 01		
253	GTO 12		
254	CLA		Print values of FN for Cases 1 and 2.
255	ADV		
256	"CASE 1"		
257	SF 12		
258	ACA		
259	PRBUF		
260	"FN="		
261	ACA		
262	CF 12		
263	FIX 2		
264	RCL 16		
265	ACX		
266	ADV		
267	ADV		
268	"CASE 2"		
269	SF 12		
270	ACA		
271	PRBUF		
272	ADV		
273	"FN="		
274	ACA		
275	CF 12		
276	RCL 17		
277	ACX		
278	ADV		
279	RTN		
280	♦LBL 12		Print value of FN for Case 3.
281	CLA		
282	"CASE 3"		
283	SF 12		
284	ACA		
285	PRBUF		
286	ADV		
287	"FN="		
288	ACA		
289	CF 12		
290	FIX 2		
291	RCL 16		
292	ACX		
293	ADV		
294	RTN		

Step/ Line	Key Entry	Key Code	Comments	Step/ Line	Key Entry	Key Code	Comments	Step/ Line	Key Entry	Key Code	Comments
295	♦LBL 20		Prints "OUT OF RANGE"								
296	"OUT OF RANGE"										
297	PRA										
298	ADV										
299	GTO "NF"										
300	.END.										

Chapter 4

Flexibility Factors, Virtual Lengths, and Intensification Factors

Program TI-59-4

Introduction:

TI-59-4 determines the stress intensification factors, virtual length, and flexibility factors for elbows, bends, and closely spaced miters and the intensification factors for welding tees, reinforced and unreinforced stub-ins, and weldolets. It will also calculate the required pad thickness to obtain the input value of the outplane intensification factor for a reinforced stub-in. In all cases, the outplane and inplane intensification factors are calculated.

Nomenclature:

The input consists of the following pieces of data. Those marked with an asterisk are required only for elbows, bends, and miters.

OD: Pipe outside diameter (in)
T: Pipe wall thickness (in)
R: Bend radius for elbow/miter (in)
*P: Internal pressure (psi)
*E: Cold modulus of elasticity (Mega psi)
I: Outplane stress intensification factor (for desired pad thickness analysis)

The output varies from one analysis to another. The notations are:

K: Flexibility factor
VL: Elbow/miter virtual length (ft)
IO: Outplane stress intensification factor
II: Inplane stress intensification factor
PT: Pad thickness (for desired pad thickness analysis) (in)

Method:

All equations are taken from Appendix D of ANSI B31.3, 1980. Virtual length is the flexibility factor multiplied by the bend radius through a 90-degree arc. The stress intensification factors are always the inplane and the outplane factors. The desired pad thickness analysis simply reverses the equations for stress intensification factor.

Limitations:

TI-59-4 does not test the pad thicknesses calculated against any restrictions set forth in the Code, either when calculating the desired pad thickness or the stress intensification factor. Virtual length is always calculated for a 90-degree arc. The program does not analyze flanged elbows. The printed value for intensification factor will never be less than 1.0.

User Instructions

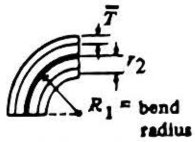
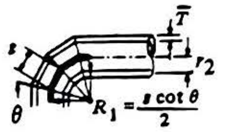
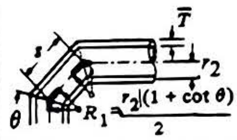
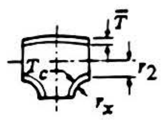
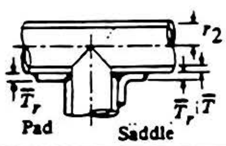
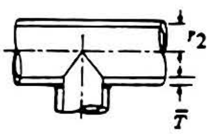
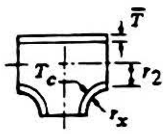
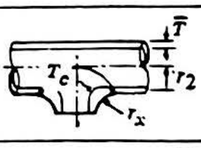
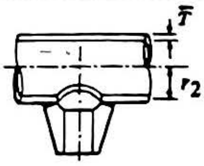
Program Number TI-59-4 **Title** Flexibility Factors

Step	Instructions	Input	Keystroke			Display
1	Read magnetic cards.					
2	Input OD.	OD	STO	0	1	OD
3	Input T.	T	STO	0	2	T
4	Input R.	R	STO	0	3	R
5	Input PT.	PT	STO	0	4	PT
6	Input P (elbows and miters only).	P	STO	0	5	P
7	Input E (elbows and miters only).	E	STO	0	6	E
	For deriving pad thickness for an input value of IO:					
	Same input as above except:	Desired IO	STO	0	4	IO
	Elbow analysis		A			K, VL, IO & II
	Miter analysis		B			K, VL, IO & II
	Tee analysis		C			IO & II
	Unreinforced stub-in analysis		D			IO & II
	Reinforced stub-in analysis		E			IO & II
	Weldolet analysis		2nd	C		IO & II
	Pad thickness analysis		2nd	E		T

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

a)(b)

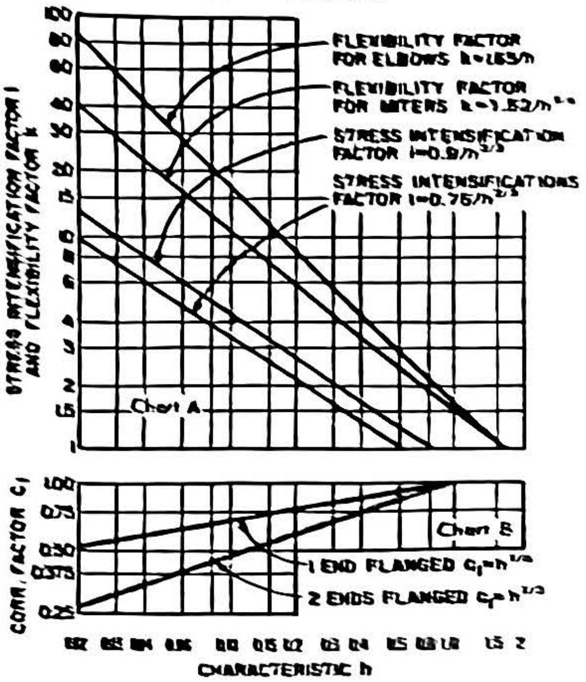
TABLE 1
FLEXIBILITY FACTOR k AND STRESS INTENSIFICATION FACTOR i

	Description	Flexibility Factor k	Stress Int. Factor[1,8] Outplane i_o	Stress Int. Factor[1,8] Inplane i_i	Flexibility Characteristic h	Sketch
	Welding elbow[1,2,3,6,9] or pipe bend	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{(r_2)^2}$	
	Closely spaced miter bend[1,2,3] $s < r_2(1+\tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\;\frac{\bar{T}s}{(r_2)^2}$	
	Single miter bend[1,2] or widely spaced miter bend $s \geq r_2(1+\tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1+\cot\theta}{2}\;\frac{\bar{T}}{r_2}$	
	Welding tee[1,2,6] per ANSI B16.9 with $r_x \geq 1/8\,D_b$ $T_c \geq 1.5\,\bar{T}$	1	$\frac{0.9}{h^{2/3}}$	$3/4\,i_o + 1/4$	$4.4\,\frac{\bar{T}}{r_2}$	
(a)	Reinforced fabricated[1,2,5] tee with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$3/4\,i_o + 1/4$	$\frac{(\bar{T}+\frac{1}{2}\bar{T}_r)^{5/2}}{\bar{T}^{3/2}\,r_2}$	
	Unreinforced[1,2] fabricated tee	1	$\frac{0.9}{h^{2/3}}$	$3/4\,i_o + 1/4$	$\frac{\bar{T}}{r_2}$	
(b)	Extruded[1,2] welding tee $r_x \geq 0.05D_b$ $T_c < 1.5\,\bar{T}$	1	$\frac{0.9}{h^{2/3}}$	$3/4\,i_o + 1/4$	$\left(1+\frac{r_x}{r_2}\right)\frac{\bar{T}}{r_2}$	
(b)	Welded-in[1,2] contour insert $r_x \geq 1/8\,D_b$ $T_c \geq 1.5\,\bar{T}$	1	$\frac{0.9}{h^{2/3}}$	$3/4\,i_o + 1/4$	$4.4\,\frac{\bar{T}}{r_2}$	
	Branch[1,2,7] welded-on fitting (integrally reinforced)	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\,\frac{\bar{T}}{r_2}$	

APPENDIX D

TABLE 1 (CONT.)
(a) FLEXIBILITY FACTOR k AND STRESS INTENSIFICATION FACTOR i

Description	Flexibility Factor k	Stress Intensification Factor i
Butt welded joint, reducer, or weld neck flange	1	1.0
Double-welded slip-on flange	1	1.2
Fillet welded joint, or socket weld flange	1	1.3
Lap joint flange (with ANSI B16.9 lap joint stub)	1	1.6
Screwed pipe joint, or screwed flange	1	2.3
Corrugated straight pipe, or corrugated or creased bend[7]	5	2.5



NOTES:

[1] The flexibility factor k in the table applies to bending in any plane. The flexibility factors k and stress intensification factors i shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter bends, and to the intersection point for tees.

(a) [2] The values of k and i can be read directly from Chart A, by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:

$\bar{T}$ = for elbows and miter bends the nominal wall thickness of the fitting
 = for tees, the nominal wall thickness of the matching pipe

T_c = the crotch thickness of tees

$\bar{T}_r$ = pad or saddle thickness

θ = one-half angle between adjacent miter axes

r_2 = mean radius of matching pipe

R_1 = bend radius of welding elbow or pipe bend

r_x = see definition in 304.3.4(c)

s = miter spacing at centerline

D_b = O.D. of branch

[3] Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1, which can be read directly from Chart B, entering with the computed h.

[4] Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

(a) [5] When $\bar{T}_r$ is $> 1\frac{1}{2}\bar{T}$, use $h = 4\frac{\bar{T}}{r_2}$

[6] The designer is cautioned that cast butt welded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

[7] The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

[8] A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.

(a) [9] In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the Table:

divide k by: $\left[1 + 6\left(\frac{P}{E_c}\right)\left(\frac{r_2}{\bar{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$ divide i by: $\left[1 + 3.25\left(\frac{P}{E_c}\right)\left(\frac{r_2}{\bar{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}\right]$

Examples of Analyses

Elbow

8.6250	OD
0.3220	T
12.0000	R
0.3220	PT
100.0000	P
27900000.00	E
7.2728	K
11.4241	VL
2.0040	IO
2.4048	II

Closely Spaced Miter

8.6250	OD
0.3220	T
12.0000	R
0.3220	PT
100.0000	P
27900000.00	E
5.2220	K
8.2026	VL
2.4048	IO
2.4048	II

Tee

8.6250	OD
0.3220	T
12.0000	R
0.3220	PT
1.8429	IO
1.6322	II

Unreinforced Stub-In

8.6250	OD
0.3220	T
12.0000	R
0.3220	PT
4.9485	IO
3.9614	II

Reinforced Stub-In

8.6250	OD
0.3220	T
12.0000	R
0.3220	PT
2.5176	IO
2.1382	II

Weldolet

8.6250	OD
0.3220	T
12.0000	R
0.3220	PT
2.2325	IO
2.2325	II

8.6250	OD
0.3220	T
2.5176	I
0.3220	PT

Desired "T" Analysis

Elbow

OD = 8.625″ | T = 0.322″ | R = 12″

PT = 0.322″ | P = 100 psi | E = 27.9EE6

$r_2 = (8.625 - .322)/2 = 4.1515$

$K = 1.65/h$

$$h = \frac{TR}{(r_2^2)} = \frac{(0.322)(12)}{(4.1515)^2} = 0.2242$$

$K = 1.65/0.2242 = 7.3596$

I inplane $= 0.9/h^{2/3} = (0.9/(0.2242)^{2/3} = 2.4387$

Pressure Modifiers:

$$\text{divide K by} \left[1 + 6\left(\frac{P}{Ec}\right)\left(\frac{r_2}{t}\right)^{7/3}\left(\frac{R}{r_2}\right)^{1/3}\right] = \left[1 + 6\left(\frac{100}{27.9EE6}\right)\left(\frac{4.1515}{0.322}\right)^{7/3}\left(\frac{12}{4.1515}\right)^{1/3}\right] = 1.0119$$

$$\text{divide I by} \left[1 + 3.25\left(\frac{P}{Ec}\right)\left(\frac{r_2}{t}\right)^{5/2}\left(\frac{R}{r_2}\right)^{2/3}\right] = \left[1 + 3.25\left(\frac{100}{27.9EE6}\right)\left(\frac{4.1515}{0.322}\right)^{5/2}\left(\frac{12}{4.1515}\right)^{2/3}\right] = 1.0141$$

$K = 7.3596/1.0119 = 7.2728$

$Ii = 2.4387/1.0141 = 2.4048$; $Io = (.75)/h^{2/3} = 2.004$

$$VL = \frac{\pi}{2}\left(\frac{12}{12}\right)7.2728 = 11.4241$$

Closely Spaced Miter

$K = 1.52/h^{5/6}$

$$h = \frac{COT\theta}{2}\ \frac{Ts}{r_2^2} \qquad \frac{(COT\theta(s)}{2} = R \therefore h = \frac{TR}{r_2^2} \nwarrow \text{same as elbow}$$

$h = 0.2242$

$K = 1.52/(.2242)^{5/6} = 5.2843$

$Io = Ii = (.9)h^{2/3} = (.9)/(.2242)^{2/3} = 2.4387$

K and I adjusters are the same as for the elbow

$$K = 5.2843/1.0119 = 5.2220$$

$$I = 2.4387/1.0141 = 2.4048$$

$$VL = \frac{\pi}{2}\left(\frac{12}{12}\right)5.2220 = 8.2026$$

Tee

$$Io = (.9/h)^{2/3};\ Ii = (3/4)(I_o) + 0.25$$

$$h = \frac{4.4T}{r_2} = \frac{4.4(0.322)}{4.1515} = 0.3413$$

$$Io = (.9)/(0.3413)^{2/3} = 1.8429;\ Ii = 1.632$$

Stub-in

$$Io = (.9)/h^{2/3};\ Ii = (3/4)(Io) + 0.25$$

$$h = T/r_2 = 0.322/4.1515 = .0776$$

$$Io = (.9)/(0.776)^{2/3} = 4.9485;\ Ii = 3.961$$

Stub-in with pad

$$Io = (.9)/h^{2/3};\ Ii = (3/4)(I_o) + 0.25$$

$$h = \frac{(T + \frac{1}{2}t_r)^{5/2}}{(T^{3/2})r_2} = \frac{[(0.322) + \frac{1}{2}(.322)]^{5/2}}{(0.322)^{3/2}(4.1515)} = 0.2137$$

$$Io = (.9)/(.2137)^{2/3} = 2.5176;\ Ii = 2.138$$

Weldolet

$$Io = (.9)/h^{2/3};\ Ii = Io$$

$$h = \frac{3.3T}{r_2} = \frac{3.3(0.322)}{4.1515} = 0.2560$$

$$Io = (.9)/(0.2560)^{2/3} = 2.2325;\ Ii = 2.2325$$

Sample Problem

Program: TI-59-4

OD = 8.625"
T = 0.322"
R = 12"
P = 100 psig
E = 27.9 EE6 psi

Step	Input	Key Stroke	Display	Printer		Comments
1	8.625	STO 01	8.265			User stores OD in R01.
2	.322	STO 02	0.322			User stores T in R02.
3	12	STO 03	12.			User stores R in R03.
4	100	STO 05	100.			User stores P in R05.
5	27900000	STO 06	27900000.			User stores E in R06.
6		A		8.6250	OD	The program calculates the
				0.3220	T	flexibility characteristic h and
				12.0000	R	stores it in R09. The mean
				0.0000	PT	radius is stored in R08. From h,
				100.0000	P	the inplane stress intensification
				27900000.00	E	factor and the flexibility factor are
						calculated and stored in R11 and
				7.2828	K	R10, respectively. The K and I
				11.4241	VL	"modifiers" are calculated, and the
						values are used to adjust the earlier
				2.0040	IO	calculated values. The virtual length
				2.4048	II	is calculated and stored in R12. The
						input and output data are printed.

Data Register Contents

REGISTER	DATA	REGISTER	DATA
00		30	
01	OD	31	
02	T	32	
03	R	33	
04	PT	34	
05	P	35	
06	E	36	
07	Used	37	
08	r_2	38	
09	h	39	
10	K	40	
11	IO	41	
12	VL	42	
13	Used	43	
14	Used	44	
15	Π	45	
16		46	
17		47	
18		48	
19		49	
20		50	
21		51	
22		52	
23		53	
24		54	
25		55	
26		56	
27		57	
28		58	
29		59	

Coding Form

Program Number TI-59-4 Title Flexibility Factors

Loc	Code	Key	Comments
000	25	CLR	Clear and stop.
001	91	R/S	
002	76	LBL	Print subroutine: Prints data with alpha flags.
003	17	B'	
004	69	OP	
005	04	04	
006	32	X:T	
007	69	OP	
008	06	06	
009	92	RTN	
010	76	LBL	Checks input value against unity, and returns the greater value.
011	30	TAN	
012	32	X:T	
013	01	1	
014	77	GE	
015	90	LST	
016	32	X:T	
017	76	LBL	
018	90	LST	
019	92	RTN	
020	76	LBL	Calculates mean radius.
021	19	D'	
022	43	RCL	
023	01	01	
024	75	−	
025	43	RCL	
026	02	02	
027	54	)	
028	55	÷	
029	02	2	
030	95	=	
031	42	STO	
032	08	08	
033	92	RTN	
034	76	LBL	Calculates II for branch connections.
035	38	SIN	
036	93	.	
037	07	7	
038	05	5	
039	65	×	
040	43	RCL	
041	11	11	
042	65	×	
043	04	4	
044	35	1/X	
045	95	=	
046	42	STO	
047	15	15	
048	92	RTN	
049	76	LBL	Calculates h for elbows and miters.
050	70	RAD	
051	86	STF	
052	01	01	
053	43	RCL	
054	02	02	
055	65		
056	43	RCL	
057	03	03	
058	75	−	
059	43	RCL	

Loc	Code	Key	Comments
060	08	08	
061	33	X²	
062	95	=	
063	92	RTN	
064	76	LBL	Main print subroutine: uses B'.
065	16	A'	
066	98	ADV	
067	43	RCL	
068	11	11	
069	71	SBR	
070	30	TAN	
071	42	STO	
072	11	11	
073	43	RCL	Test IO and II for values less than 1.
074	15	15	
075	71	SBR	
076	30	TAN	
077	42	STO	
078	15	15	
079	25	CLR	
080	58	FIX	
081	04	04	
082	43	RCL	
083	01	01	
084	32	X:T	
085	03	3	
086	02	2	
087	01	1	
088	06	6	
089	17	B'	Print "OD."
090	43	RCL	
091	02	02	
092	32	X:T	
093	03	3	
094	07	7	
095	17	B'	Print "T".
096	87	IFF	If analysis is for desired pad thickness, go to LOG.
097	02	02	
098	28	LOG	
099	43	RCL	
100	03	03	
101	32	X:T	
102	03	3	
103	05	5	
104	17	B'	Print "R".
105	43	RCL	
106	04	04	
107	32	X:T	
108	03	3	
109	03	3	
110	03	3	
111	07	7	
112	17	B'	Print "PT."
113	22	INV	If the analysis is for a branch connection go to LNX.
114	87	IFF	
115	01	01	
116	23	LNX	
117	43	RCL	
118	05	05	
119	32	X:T	

Loc	Code	Key	Comments
120	03	3	
121	03	3	
122	17	B'	Print "P."
123	43	RCL	
124	06	06	
125	32	X:T	
126	01	1	
127	07	7	
128	17	B'	Print "E."
129	98	ADV	
130	43	RCL	
131	10	10	
132	32	X:T	
133	02	2	
134	06	6	
135	17	B'	Print "K."
136	43	RCL	
137	12	12	
138	32	X:T	
139	04	4	
140	02	2	
141	02	2	
142	07	7	
143	17	B'	Print "VL."
144	76	LBL	
145	23	LNX	
146	98	ADV	
147	43	RCL	
148	11	11	
149	32	X:T	
150	02	2	
151	04	4	
152	00	0	
153	01	1	
154	17	B'	Print "IO."
155	43	RCL	
156	15	15	
157	32	X:T	
158	02	2	
159	04	4	
160	02	2	Print "II."
161	04	4	
162	17	B'	
163	22	INV	
164	58	FIX	
165	81	RST	Reset.
166	76	LBL	Calculate IO.
167	78	Σ+	
168	42	STO	
169	09	09	
170	45	Y^X	
171	01	1	
172	93	.	
173	05	5	
174	35	1/X	
175	55	÷	
176	93	.	
177	09	9	
178	95	=	
179	35	1/X	

Loc	Code	Key	Comments
180	42	STO	
181	11	11	
182	92	RTN	
183	76	LBL	Adjust K, IO, and II for pressure.
184	44	SUM	
185	43	RCL	
186	05	05	
187	55	÷	
188	43	RCL	
189	06	06	
190	65	×	
191	42	STO	
192	13	13	
193	06	6	
194	65	×	
195	53	(	
196	43	RCL	
197	08	08	
198	55	÷	
199	43	RCL	
200	02	02	
201	54	)	
202	42	STO	
203	14	14	
204	45	Y^X	
205	53	(	
206	07	7	
207	55	÷	
208	03	3	
209	54	)	
210	65	×	
211	53	(	
212	43	RCL	
213	03	03	
214	55	÷	
215	43	RCL	
216	08	08	
217	54	)	
218	42	STO	
219	07	07	
220	45	Y^X	
221	03	3	
222	35	1/X	
223	85	+	
224	01	1	
225	95	=	
226	35	1/X	
227	49	PRD	
228	10	10	
229	01	1	
230	85	+	
231	03	3	
232	93	.	
233	02	2	
234	05	5	
235	65	×	
236	43	RCL	
237	13	13	
238	65	×	
239	43	RCL	
240	14	14	
241	45	Y^X	
242	02	2	
243	93	.	
244	05	5	
245	65	×	
246	43	RCL	
247	07	07	
248	45	Y^X	
249	01	1	
250	93	.	
251	05	5	
252	35	1/X	
253	95	=	
254	35	1/X	
255	49	PRD	
256	11	11	
257	49	PRD	
258	15	15	
259	43	RCL	
260	11	11	
261	48	EXC	
262	15	15	
263	42	STO	
264	11	11	
265	92	RTN	
266	76	LBL	Calculate VL.
267	24	CE	
268	43	RCL	
269	10	10	
270	55	÷	
271	02	2	
272	04	4	
273	65	×	
274	89	π	
275	65	×	
276	43	RCL	
277	03	03	
278	95	=	
279	42	STO	
280	12	12	
281	92	RTN	
282	76	LBL	Elbow analysis.
283	11	A	
284	19	D'	
285	71	SBR	
286	70	RAD	
287	71	SBR	
288	78	Σ+	
289	55	÷	
290	01	1	
291	93	.	
292	02	2	
293	95	=	
294	42	STO	
295	15	15	
296	01	1	
297	93	.	
298	06	6	
299	05	5	
300	55	-	
301	43	RCL	
302	09	09	
303	95	=	
304	42	STO	
305	10	10	
306	71	SBR	
307	44	SUM	
308	71	SBR	
309	24	CE	
310	16	A'	
311	76	LBL	Miter analysis.
312	12	B	
313	19	D'	
314	71	SBR	
315	70	RAD	
316	71	SBR	
317	78	Σ+	
318	42	STO	
319	15	15	
320	01	1	
321	93	.	
322	05	5	
323	02	2	
324	55	÷	
325	43	RCL	
326	09	09	
327	45	Y^X	
328	01	1	
329	93	.	
330	02	2	
331	35	1/X	
332	95	=	
333	42	STO	
334	10	10	
335	71	SBR	
336	44	SUM	
337	71	SBR	
338	24	CE	
339	16	A'	
340	76	LBL	Tee analysis.
341	13	C	
342	19	D'	
343	55	÷	
344	43	RCL	
345	02	02	
346	55	÷	
347	04	4	
348	93	.	
349	04	4	
350	95	=	
351	35	1/X	
352	71	SBR	
353	78	Σ+	
354	71	SBR	
355	38	SIN	
356	16	A'	
357	76	LBL	Unreinforced stub-in analysis.
358	14	D	
359	19	D'	

Loc	Code	Key	Comments
360	55	÷	
361	43	RCL	
362	02	02	
363	95	=	
364	35	1/X	
365	71	SBR	
366	78	Σ+	
367	71	SBR	
368	38	SIN	
369	16	A'	
370	76	LBL	Reinforced stub-in.
371	15	E	
372	19	D'	
373	43	RCL	
374	02	02	
375	85	+	
376	43	RCL	
377	04	04	
378	55	÷	
379	02	2	
380	54	)	
381	45	YX	
382	02	2	
383	93	.	
384	05	5	
385	55	÷	
386	43	RCL	
387	02	02	
388	45	YX	
389	01	1	
390	93	.	
391	05	5	
392	55	÷	
393	43	RCL	
394	08	08	
395	95	=	
396	71	SBR	
397	78	Σ+	
398	71	SBR	
399	38	SIN	
400	16	A'	
401	76	LBL	Calculate required pad thickness given IO.
402	10	E'	
403	86	STF	
404	02	02	
405	19	D'	
406	43	RCL	
407	04	04	
408	35	1/X	
409	65	×	
410	93	.	
411	09	9	
412	54	)	
413	22	INV	
414	45	YX	
415	01	1	
416	93	.	
417	05	5	
418	35	1/X	
419	65	×	
420	43	RCL	
421	08	08	
422	65	×	
423	43	RCL	
424	02	02	
425	45	YX	
426	01	1	
427	93	.	
428	05	5	
429	95	=	
430	22	INV	
431	45	YX	
432	02	2	
433	93	.	
434	05	5	
435	75	-	
436	43	RCL	
437	02	02	
438	54	)	
439	65	×	
440	02	2	
441	95	=	
442	42	STO	
443	16	16	
444	16	A'	
445	76	LBL	
446	28	LOG	
447	43	RCL	
448	04	04	
449	32	X:T	
450	02	2	
451	04	4	
452	17	B'	
453	98	ADV	
454	43	RCL	
455	16	16	
456	32	X:T	
457	03	3	
458	03	3	
459	03	3	
460	07	7	
461	17	B'	
462	81	RST	
463	76	LBL	Weldolet analysis.
464	18	C'	
465	19	D'	
466	55	÷	
467	43	RCL	
468	02	02	
469	55	÷	
470	03	3	
471	93	.	
472	03	3	
473	95	=	
474	35	1/X	
475	71	SBR	
476	78	Σ+	
477	42	STO	
478	15	15	
479	16	A'	

Program HP-41CV-4: Flexibility Factors, Virtual Lengths, and Intensification Factors

Introduction:

HP-41CV-4 determines the stress intensification factors, virtual length, and flexibility factors for elbows, bends and closely spaced miters and the intensification factors for welding tees, reinforced and unreinforced stub-ins, and weldolets, It will also calculate the required pad thickness to obtain the input value of the outplane intensification factor for a reinforced stub-in. In all cases, the outplane and inplane intensification factors are calculated.

Nomenclature:

The input consists of the following pieces of data. Those marked with an asterisk are required only for elbows, bends, and miters.

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- R: Bend radius for elbow/miter (in)
- *P: Internal pressure (psi)
- *E: Cold modulus of elasticity (Mega psi)
- Io: Outplane stress intensification factor (for desired pad thickness analysis)

The output varies from one analysis to another. The notations are:

- K: Flexibility factor
- Lv: Elbow/miter virtual length (ft)
- Io: Outplane stress intensification factor
- Ii: Inplane stress intensification factor
- PAD: Pad thickness (for desired pad thickness analysis) (in)

Method:

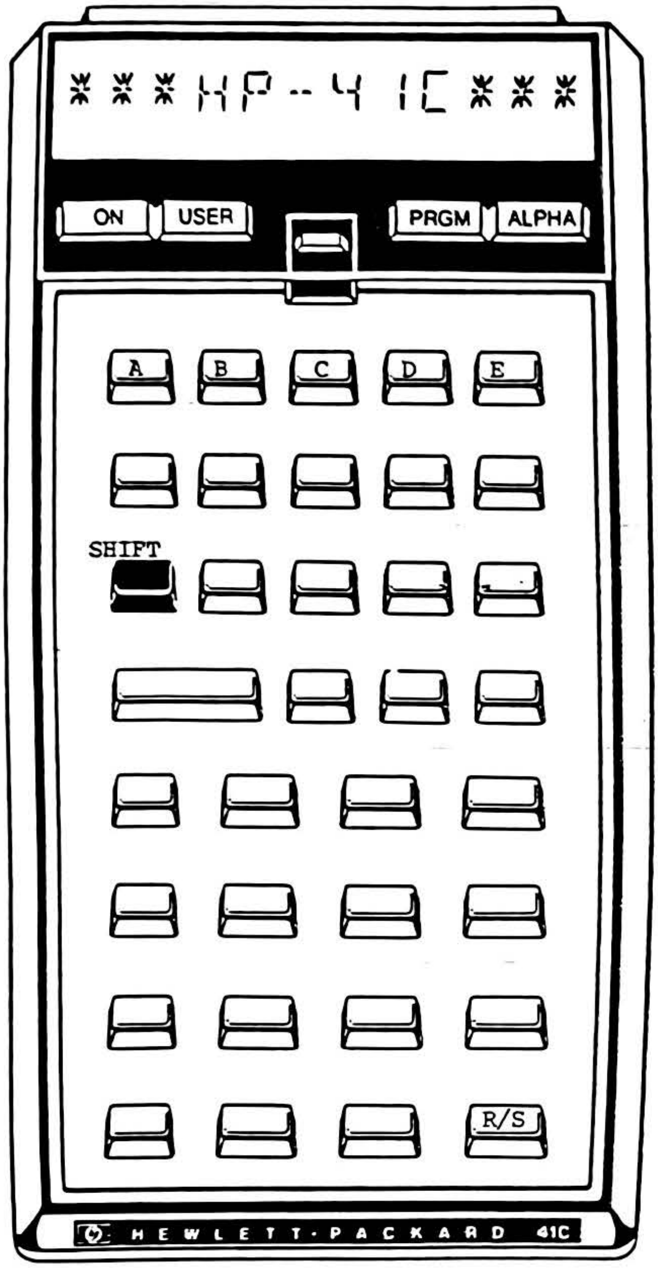
All equations are taken from Appendix D of ANSI B31.3, 1980. Virtual length is the flexibility factor multiplied by the bend radius through a 90-degree arc. The stress intensification factors are always the inplane and the outplane factors. The desired pad thickness analysis simply reverses the equations for the stress intensification factor.

Limitations:

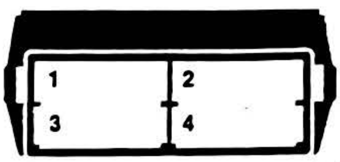
HP-41CV-4 does not test the pad thicknesses calculated against any restrictions set forth in the Code, either when calculating the desired pad thickness or the stress intensification factor. Virtual length is always calculated for a 90-degree arc. The program does not analyze flanged elbows. The printed value for intensification factor will never be less than 1.0.

Keyboard Card Labeling

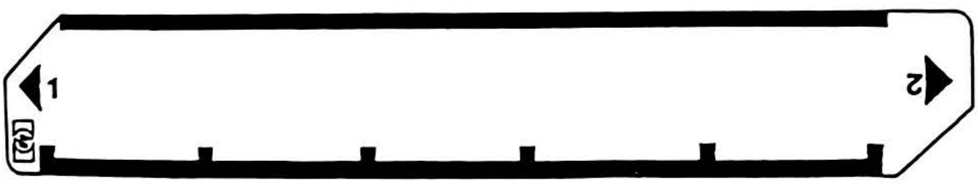
KEYBOARD



SYSTEM CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-4 **Title** Flexibility Factors

Step	Instructions	Input	Keystroke	Display
	Elbow Analysis		A	OD=
1	Input OD.	OD	R/S	T=
2	Input T.	T	R/S	R=
3	Input R.	R	R/S	P=
4	Input P.	P	R/S	E=
5	Input E.	E	R/S	
				K
				Lv
				Ii
				Io
	Miter Analysis		B	OD=
1	Input OD.	OD	R/S	T=
2	Input T.	T	R/S	R=
3	Input R.	R	R/S	P=
4	Input P.	P	R/S	E=
5	Input E.	E	R/S	
				K
				Lv
				Ii
				Io
	Tee Analysis		C	OD=
1	Input OD.	OD	R/S	T=
2	Input T.	T	R/S	
				Ii
				Io
	Stub-in Analysis		D	OD=
1	Input D.	OD	R/S	T=
2	Input T.	T	R/S	
				Ii
				Io
	Reinforced Stub-in Analysis		E	OD=
1	Input OD.	OD	R/S	T=
2	Input T.	T	R/S	PAD=
3	Input PAD.	PAD	R/S	
				Ii
				Io
	Weldolet Analysis		Shift C	OD=
1	Input OD.	OD	R/S	T=
2	Input T.	T	R/S	
				Ii
				Io
	Required Pad Analysis		Shift E	OD=
1	Input OD.	OD	R/S	T=
2	Input T.	T	R/S	IO=
3	Input Io.	Io	R/S	
				PAD

Registers, Flags, Assignments

Program Number HP-41CV-4 **Title** Flexibility Factors

DATA REGISTERS

00	
01	OD
02	T
03	R
04	PAD or I req'd
05	P
06	E
07	Lv
08	Mean radius
09	h
10	K
11	Ii
12	Io
13	K modifier
14	I modifier
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	
38	

DATA REGISTERS

39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates

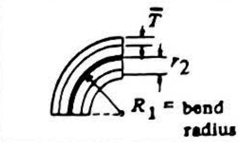
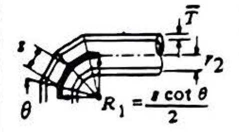
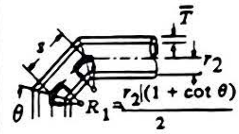
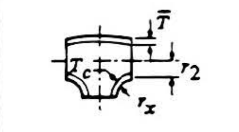
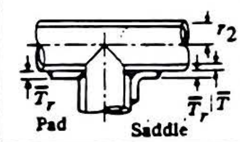
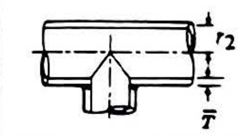
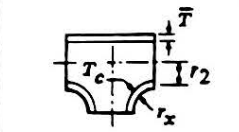
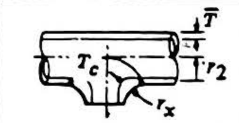
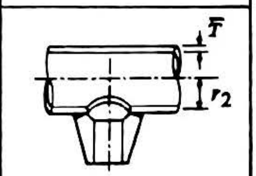
ASSIGNMENTS

Label	Key	Function	Key
AA	11 (A)		
BB	12 (B)		
CC	13 (C)		
DD	14 (D)		
EE	15 (E)		
SC	-13 (C')		
SE	-15 (E')		

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

a)(b)

TABLE 1
FLEXIBILITY FACTOR k AND STRESS INTENSIFICATION FACTOR i

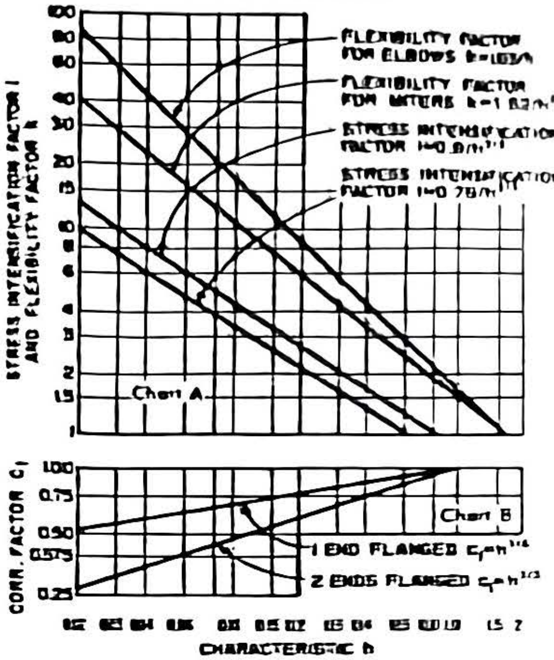
	Description	Flexibility Factor k	Stress Int. Factor[1,8] Outplane i_o	Stress Int. Factor[1,8] Inplane i_i	Flexibility Characteristic h	Sketch
	Welding elbow[1,2,3,6,9] or pipe bend	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{(r_2)^2}$	
	Closely spaced miter bend[1,2,3] $s < r_2 (1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\text{Cot}\,\theta}{2} \frac{\bar{T}s}{(r_2)^2}$	
	Single miter bend[1,2] or widely spaced miter bend $s \geq r_2 (1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \text{Cot}\,\theta}{2} \frac{\bar{T}}{r_2}$	
	Welding tee[1,2,6] per ANSI B16.9 with $r_x \geq 1/8\, D_b$ $T_c \geq 1.5\, \bar{T}$	1	$\frac{0.9}{h^{2/3}}$	$3/4\, i_o + 1/4$	$4.4 \frac{\bar{T}}{r_2}$	
(a)	Reinforced fabricated[1,2,5] tee with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$3/4\, i_o + 1/4$	$\frac{(\bar{T} + \frac{1}{2}\bar{T}_r)^{5/2}}{\bar{T}^{3/2}\, r_2}$	
	Unreinforced[1,2] fabricated tee	1	$\frac{0.9}{h^{2/3}}$	$3/4\, i_o + 1/4$	$\frac{\bar{T}}{r_2}$	
(b)	Extruded[1,2] welding tee $r_x \geq 0.05 D_b$ $T_c < 1.5\, \bar{T}$	1	$\frac{0.9}{h^{2/3}}$	$3/4\, i_o + 1/4$	$\left(1 + \frac{r_x}{r_2}\right) \frac{\bar{T}}{r_2}$	
(b)	Welded-in[1,2] contour insert $r_x \geq 1/8\, D_b$ $T_c \geq 1.5\, \bar{T}$	1	$\frac{0.9}{h^{2/3}}$	$3/4\, i_o + 1/4$	$4.4 \frac{\bar{T}}{r_2}$	
	Branch[1,2,7] welded-on fitting (integrally reinforced)	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3 \frac{\bar{T}}{r_2}$	

APPENDIX D

TABLE 1 (CONT.)

(a) **FLEXIBILITY FACTOR k AND STRESS INTENSIFICATION FACTOR i**

Description	Flexibility Factor k	Stress Intensification Factor i
Butt welded joint, reducer, or weld neck flange	1	1.0
Double welded slip-on flange	1	1.2
Fillet welded joint, or socket weld flange	1	1.3
Lap joint flange (with ANSI B16.5 lap joint stub)	1	1.6
Screwed pipe joint, or screwed flange	1	2.3
Corrugated straight pipe, or corrugated or creased bend[4]	5	2.5



NOTES:

[1] The flexibility factor k in the table applies to bending in any plane. The flexibility factors k and stress intensification factors i shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter bends, and to the intersection point for tees.

(a) [2] The values of k and i can be read directly from Chart A, by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:

$\bar{T}$ = for elbows and miter bends the nominal wall thickness of the fitting
= for tees, the nominal wall thickness of the matching pipe

T_c = the crotch thickness of tees

$\bar{T}_r$ = pad or saddle thickness

θ = one-half angle between adjacent miter axes

r_2 = mean radius of matching pipe

R_1 = bend radius of welding elbow or pipe bend

r_x = see definition in 304.3.4(c)

s = miter spacing at centerline

D_b = O.D. of branch

[3] Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1, which can be read directly from Chart B, entering with the computed h.

[4] Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

(a) [5] When $\bar{T}_r$ is $> 1\frac{1}{2}\bar{T}$, use $h = 4\frac{\bar{T}}{r_2}$

[6] The designer is cautioned that cast butt welded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

[7] The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

[8] A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.

(a) [9] In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the Table:

divide k by: $\left[1 + 6\left(\frac{P}{E_c}\right)\left(\frac{r_2}{\bar{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$ divide i by: $\left[1 + 3.25\left(\frac{P}{E_c}\right)\left(\frac{r_2}{\bar{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}\right]$

ELBOW

OD=8.625
T=0.322
R=12.000
P=100.000
E=27.900

K=7.273
Lv=11.424
Ii=2.405
Io=2.004

MITER

OD=8.625
T=0.322
R=12.000
P=100.000
E=27.900

K=5.222
Lv=8.203
Ii=2.405
Io=2.405

TEE

OD=8.625
T=0.322

Ii=1.632
Io=1.843

STUB-IN

OD=8.625
T=0.322

Ii=3.961
Io=4.949

RE. PAD

OD=8.625
T=0.322
PAD=0.322

Ii=2.138
Io=2.518

WELDOLET

OD=8.625
T=0.322

Ii=2.233
Io=2.233

REQ,D PAD

OD=8.625
T=0.322
IO=2.518

PAD=0.322

	OD = 8.625″	PT = 0.322″	$r_2 = (8.625 - .322)/2 = 4.1515$
	T = 0.322″	P = 100 psi	
Elbow	R = 12″	E = 27.9 EE6	

$K = 1.65/h$

$$h = \frac{TR}{(r_2^2)} = \frac{(0.322)(12)}{(4.1515)^2} = 0.2242$$

$K = 1.65/0.2242 = 7.3596$

$I \text{ inplane} = 0.9/h^{2/3} = (0.9/(0.2242)^{2/3} = 2.4387$

Pressure Modifiers:

$$\text{divide K by}\left[1 + 6\left(\frac{P}{Ec}\right)\left(\frac{r_2}{t}\right)^{7/3}\left(\frac{R}{r_2}\right)^{1/3}\right] = \left[1 + 6\left(\frac{100}{27.9EE6}\right)\left(\frac{4.1515}{0.322}\right)^{7/3}\left(\frac{12}{4.1515}\right)^{1/3}\right] = 1.0119$$

$$\text{divide I by}\left[1 + 3.25\left(\frac{P}{Ec}\right)\left(\frac{r_2}{t}\right)^{5/2}\left(\frac{R}{r_2}\right)^{2/3}\right] = \left[1 + 3.25\left(\frac{100}{27.9EE6}\right)\left(\frac{4.1515}{0.322}\right)^{5/2}\left(\frac{12}{4.1515}\right)^{2/3}\right] = 1.0141$$

$K = 7.3596/1.0119 = 7.2728$

$Ii = 2.4387/1.0141 = 2.4048;\ Io = (.75)/h^{2/3} = 2.004$

$$VL = \frac{\pi}{2}\left(\frac{12}{12}\right)7.2728 = 11.4241$$

Closely Spaced Miter

$K = 1.52/h^{5/6}$

$$h = \frac{COT\theta}{2}\ \frac{Ts}{r_2^2} \qquad \frac{(COT\theta(s)}{2} = R \therefore h = \frac{TR}{r_2^2}$$ ↖ same as elbow

$h = 0.2242$

$K = 1.52/(.2242)^{5/6} = 5.2843$

$Io = Ii = (.9)h^{2/3} = (.9)/(.2242)^{2/3} = 2.4387$

K and I adjusters are the same as for the elbow

$K = 5.2843/1.0119 = 5.2220$

$I = 2.4387/1.0141 = 2.4048$

$$VL = \frac{\pi}{2}\left(\frac{12}{12}\right)5.2220 = 8.2026$$

Tee

$Io = (.9/h)^{2/3}$; $Ii = (3/4)(I_o) + 0.25$

$$h = \frac{4.4T}{r_2} = \frac{4.4(0.322)}{4.1515} = 0.3413$$

$Io = (.9)/(0.3413)^{2/3} = 1.8429$; $Ii = 1.632$

Stub-in

$Io = (.9)/h^{2/3}$; $Ii = (3/4)(Io) + 0.25$

$h = T/r_2 = 0.322/4.1515 = .0776$

$Io = (.9)/(0.776)^{2/3} = 4.9485$; $Ii = 3.961$

Stub-in with pad

$Io = (.9)/h^{2/3}$; $Ii = (3/4)(I_o) + 0.25$

$$h = \frac{(T + \frac{1}{2}t_r)^{5/2}}{(T^{3/2})r_2} = \frac{[(0.322) + \frac{1}{2}(.322)]^{5/2}}{(0.322)^{3/2}(4.1515)} = 0.2137$$

$Io = (.9)/(.2137)^{2/3} = 2.5176$; $Ii = 2.138$

Weldolet

$Io = (.9)/h^{2/3}$; $Ii = Io$

$$h = \frac{3.3T}{r_2} = \frac{3.3(0.322)}{4.1515} = 0.2560$$

$Io = (.9)/(0.2560)^{2/3} = 2.2325$; $Ii = 2.2325$

Sample Problem

Program HP-41CV-4 Title Flexibility Factors

Sample Problem (Sketch if Desired)

Input	Function	Display	Comments
8.625	A	OD=	
.322	R/S	T=	Each analysis will prompt the user for all the information needed for that set of equations.
12	R/S	R=	
100	R/S	P=	
27.9	R/S	E=	
	R/S	K = 7.273	
		Lv = 11.424	
		Ii = 2.405	
		Io = 2.004	

Coding Form

Program Number HP-41CV-4 Title Flexibility Factors

Step/Line Key Entry	Key Code	Comments
01♦LBL "AA"		Elbow analysis.
02 FIX 3		
03 SF 12		
04 "ELBOW"		
05 PRA		
06 CF 12		
07 ADV		
08 "OD="		Input routine.
09 PROMPT		
10 STO 01		
11 ARCL 01		
12 PRA		
13 "T="		
14 PROMPT		
15 STO 02		
16 ARCL 02		
17 PRA		
18 "R="		
19 PROMPT		
20 STO 03		
21 ARCL 03		
22 PRA		
23 "P="		
24 PROMPT		
25 STO 05		
26 ARCL 05		
27 PRA		
28 "E="		
29 PROMPT		
30 STO 06		
31 ARCL 06		
32 PRA		
33 ADV		
34 RCL 01		Calculate mean radius.
35 RCL 02		
36 -		
37 2		
38 /		
39 STO 08		
40 X↑2		Calculate h.
41 RCL 02		
42 RCL 03		
43 *		
44 X<>Y		
45 /		
46 STO 09		
47 2		
48 ENTER↑		
49 3		

Step/Line Key Entry	Key Code	Comments
50 /		Calculate Io.
51 Y↑X		
52 .9		
53 X<>Y		
54 /		
55 STO 11		
56 .75		Calculate Ii.
57 *		
58 .9		
59 /		
60 STO 12		
61 1.65		Calculate K.
62 RCL 09		
63 /		
64 STO 10		
65 RCL 03		Calculate Lv.
66 *		
67 12		
68 /		
69 PI		
70 *		
71 2		
72 /		
73 STO 07		
74 XEQ D		Adjust for pressure.
75 GTO B		Go to printer.
76♦LBL "BB"		Miter analysis.
77 FIX 3		
78 "MITER"		
79 SF 12		
80 PRA		
81 CF 12		
82 ADV		
83 "OD="		
84 PROMPT		Input routine.
85 STO 01		
86 ARCL 01		
87 PRA		
88 "T="		
89 PROMPT		
90 STO 02		
91 ARCL 02		
92 PRA		
93 "R="		
94 PROMPT		
95 STO 03		
96 ARCL 03		
97 PRA		
98 "P="		

Step/Line Key Entry	Key Code	Comments
99 PROMPT		
100 STO 05		
101 ARCL 05		
102 PRA		
103 "E="		
104 PROMPT		
105 STO 06		
106 ARCL 06		
107 PRA		
108 ADV		
109 RCL 01		Calculate mean radius.
110 RCL 02		
111 -		
112 2		
113 /		
114 STO 08		
115 X↑2		Calculate h.
116 RCL 02		
117 RCL 03		
118 *		
119 X<>Y		
120 /		
121 STO 09		
122 2		Calculate Io (same as Ii).
123 ENTER↑		
124 3		
125 /		
126 Y↑X		
127 .9		
128 X<>Y		
129 /		
130 STO 11		
131 STO 12		
132 1.52		Calculate K.
133 RCL 09		
134 5		
135 ENTER↑		
136 6		
137 /		
138 Y↑X		
139 /		
140 STO 10		
141 RCL 03		Calculate VL.
142 *		
143 12		
144 /		
145 PI		
146 *		
147 2		

Step/Line	Key Entry	Key Code	Comments
148	/		
149	STO 07		Adjust for pressure. Go to printer.
150	XEQ D		
151	GTO B		
152	♦LBL "CC"		Tee analysis.
153	FIX 3		
154	SF 12		
155	"TEE"		
156	PRA		Input routine.
157	CF 12		
158	"OD="		
159	PROMPT		
160	STO 01		
161	ARCL 01		
162	PRA		
163	"T="		
164	PROMPT		
165	STO 02		
166	ARCL 02		
167	PRA		
168	ADV		
169	RCL 01		Calculate mean radius.
170	RCL 02		
171	-		
172	2		
173	/		
174	STO 08		
175	RCL 02		Calculate h.
176	/		
177	1/X		
178	4.4		
179	*		
180	STO 09		
181	2		Calculate Ii.
182	ENTER↑		
183	3		
184	/		
185	Y↑X		
186	.9		
187	X<>Y		
188	/		
189	STO 12		
190	.75		Calculate Io.
191	*		
192	.25		
193	+		
194	STO 11		
195	GTO A		Go to printer.
196	♦LBL "DD"		

Step/Line	Key Entry	Key Code	Comments
197	FIX 3		
198	SF 12		
199	"STUB-IN"		
200	PRA		Stub-in analysis.
201	CF 12		
202	ADV		
203	"OD="		
204	PROMPT		Input routine.
205	STO 01		
206	ARCL 01		
207	PRA		
208	"T="		
209	PROMPT		
210	STO 02		
211	ARCL 02		
212	PRA		
213	ADV		
214	RCL 01		Calculate mean radius.
215	RCL 02		
216	-		
217	2		
218	/		
219	STO 08		
220	RCL 02		Calculate h.
221	X<>Y		
222	/		
223	STO 09		
224	2		Calculate Ii.
225	ENTER↑		
226	3		
227	/		
228	Y↑X		
229	.9		
230	X<>Y		
231	/		
232	STO 12		
233	.75		Calculate Io.
234	*		
235	.25		
236	+		
237	STO 11		
238	GTO A		Go to printer.
239	♦LBL "EE"		Reinforcing pad analysis.
240	FIX 3		
241	SF 12		
242	"RE. PAD"		
243	PRA		
244	CF 12		
245	ADV		

Step/Line	Key Entry	Key Code	Comments
246	"OD="		Input routine.
247	PROMPT		
248	STO 01		
249	ARCL 01		
250	PRA		
251	"T="		
252	PROMPT		
253	STO 02		
254	ARCL 02		
255	PRA		
256	"PAD="		
257	PROMPT		
258	STO 04		
259	ARCL 04		
260	PRA		
261	ADV		
262	RCL 01		Calculate mean radius.
263	RCL 02		
264	-		
265	2		
266	/		
267	STO 08		
268	RCL 02		Calculate h.
269	RCL 04		
270	.5		
271	*		
272	+		
273	2.5		
274	Y↑X		
275	RCL 02		
276	1.5		
277	Y↑X		
278	/		
279	RCL 08		
280	/		
281	STO 09		
282	2		Calculate Ii.
283	ENTER↑		
284	3		
285	/		
286	Y↑X		
287	.9		
288	X<>Y		
289	/		
290	STO 12		
291	.75		Calculate Io.
292	*		
293	.25		
294	+		

Step/Line	Key Entry	Key Code	Comments
295	STO 11		
296	GTO A		Go to printer.
297	◆LBL "SC"		Weldolet analysis.
298	FIX 3		
299	SF 12		
300	"WELDOLET"		
301	PRA		
302	CF 12		
303	ADV		
304	"OD="		Input routine.
305	PROMPT		
306	STO 01		
307	ARCL 01		
308	PRA		
309	"T="		
310	PROMPT		
311	STO 02		
312	ARCL 02		
313	PRA		
314	ADV		
315	RCL 01		Calculate mean radius.
316	RCL 02		
317	-		
318	2		
319	/		
320	STO 08		
321	RCL 02		Calculate h.
322	X<>Y		
323	/		
324	3.3		
325	*		
326	STO 09		
327	2		Calculate Ii.
328	ENTER↑		
329	3		
330	/		
331	Y↑X		
332	.9		
333	X<>Y		
334	/		
335	STO 12		
336	STO 11		Calculate Io.
337	GTO A		
338	◆LBL "SE"		
339	FIX 3		
340	SF 12		
341	"REQ,D PAD"		Go to printer.
342	PRA		
343	CF 12		

Step/Line	Key Entry	Key Code	Comments
344	ADV		
345	"OD="		Required pad thickness analysis.
346	PROMPT		
347	STO 01		
348	ARCL 01		
349	PRA		
350	"T="		
351	PROMPT		Input routine.
352	STO 02		
353	ARCL 02		
354	PRA		
355	"IO="		
356	PROMPT		
357	STO 04		
358	ARCL 04		
359	PRA		
360	ADV		
361	RCL 01		
362	RCL 02		
363	-		
364	2		
365	/		Calculate mean radius.
366	STO 08		
367	RCL 04		
368	1/X		
369	.9		
370	*		
371	1.5		Calculate required pad from input Io.
372	Y↑X		
373	RCL 02		
374	1.5		
375	Y↑X		
376	*		
377	RCL 08		
378	*		
379	.4		
380	Y↑X		
381	RCL 02		
382	-		
383	2		
384	*		
385	STO 11		
386	"PAD="		
387	ARCL 11		
388	PRA		
389	ADV		
390	ADV		Print pad thickness.
391	CLX		
392	STOP		

Step/Line	Key Entry	Key Code	Comments
393	◆LBL D		
394	6		
395	RCL 05		
396	RCL 06		
397	1 E6		Pressure adjustment routine for elbows and miters.
398	*		
399	/		
400	*		
401	RCL 03		
402	RCL 02		
403	/		
404	7		
405	ENTER↑		
406	3		
407	/		
408	Y↑X		
409	*		
410	RCL 03		
411	RCL 08		
412	/		
413	1		
414	ENTER↑		Calculate K adjustment.
415	3		
416	/		
417	Y↑X		
418	*		
419	1		
420	+		
421	STO 13		
422	ST/ 10		
423	ST/ 07		
424	3.25		
425	RCL 05		Adjust K and Lv.
426	RCL 06		
427	1 E6		
428	*		
429	/		
430	*		
431	RCL 08		
432	RCL 02		Calculate I adjustment.
433	/		
434	2.5		
435	Y↑X		
436	*		
437	RCL 03		
438	RCL 08		
439	/		
440	2		
441	ENTER↑		

Step/Line	Key Entry	Key Code	Comments
442	3		
443	/		
444	Y↑X		
445	*		
446	1		
447	+		
448	STO 14		
449	ST/ 11		
450	ST/ 12		
451	RTN		
452♦	LBL B		Adjust I_o and I_i.
453	"K="		
454	ARCL 10		
455	PRA		
456	"L"		Print routine for K and L_v.
457	ACA		
458	SF 13		
459	"V"		
460	ACA		
461	CF 13		
462	"="		
463	ARCL 07		
464	ACA		
465	PRBUF		
466♦	LBL A		
467	"I"		Print routine for I_o and I_i test-calculated results to see if I_i or I_o are less than 1.0. Print greater.
468	ACA		
469	SF 13		
470	"I"		
471	ACA		
472	CF 13		
473	"="		
474	1		
475	RCL 11		
476	X>Y?		
477	GTO 18		
478	X<>Y		
479♦	LBL 18		
480	ARCL X		
481	ACA		
482	PRBUF		
483	"I"		
484	ACA		
485	SF 13		
486	"O"		
487	ACA		
488	CF 13		
489	"="		
490	1		
491	RCL 12		
492	X>Y?		
493	GTO 19		
494	X<>Y		
495♦	LBL 19		
496	ARCL X		
497	ACA		
498	PRBUF		
499	ADV		
500	ADV		
501	CLA		
502	CLX		
503	STOP		
504	.END.		

Part II

Pipe Stress

Flanged Connection Bolt Tensioning

Program TI-59-5

Introduction:

TI-59-5 performs calculations to determine the minimum required bolt tensioning for flanged joints to insure a leak-free connection. The program determines the maximum applied forces that tend to open the joint based on internal pressure, thermal and dead load bending moments, and the differential expansion/contraction of the flanges and bolts. TI-59-5 also determines the minimum bolt load needed to seat the gasket and the maximum bolt stress at installation.

Nomenclature:

Twenty-one pieces of data must be input for the analysis:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- SGF: Specific gravity of fluid
- ID: Insulation density (lb/ft^3)
- IT: Insulation thickness (in)
- P: Internal pressure (psig)
- I: Maximum stress intensification factor
- SC: Cold allowable stress (psi)
- G: Mean diameter of gasket (G dimension)
- B: Effective gasket width (b dimension) (in)
- M: Gasket factor
- SH: Hot allowable stress (psi)
- Y: Gasket seating stress (psi)
- eF: Coefficient of thermal expansion for flanges (μin/in/°F)
- TF: Operating temperature of flanges (°F)
- eB: Coefficient of thermal expansion for bolts (μin/in/°F)
- TB: Operating temperature of bolts (°F)
- AB: Tensile area of bolts (in^2)
- EB: Young's Modulus of elasticity of bolts (Mega psi)
- NO: Number of bolts per flange
- TI: Installation temperature (°F)

The data G, B, M, and Y are defined in ASME Section VIII, Div. 1, Appendix 2.

Three user keys execute the program.

- A: Input data
- B: Execute program
- E: Initialize program

The following variables are calculated by the program:

- Z: Pipe section modulus (in^3)
- L: Maximum dead load span (in)
- SE: Allowable stress range (1.25SC + .25SH) (psi)
- W: Pipe operating weight per inch

Method:

TI-59-5 calculates four distinct forces that will tend to open the flanged joint. These are due to (1) internal pressure (2) thermal bending moment, (3) dead load bending moment, and (4) the differential expansion or contraction between the flanges and the bolts. Each of these forces are detailed below.

(1) Force due to Internal Pressure

The formula for this force is:

$$\frac{(\pi/4)(G^2)(P) + 2(B)(\pi)(G)(M)(P)}{NO.}$$

This formula is found in ASME Section VIII, Div. 1, Appendix 2. This force is positive as long as P is positive.

(2) Force due to Thermal Bending Moment

This force is a "worst case" number that assumes that the worst bending moment allowed will occur at the flanged connection. The stress range allowable is divided by the stress intensification factor to obtain the nominal stress value. The formula is:

$$F2 = \left|\frac{4(Z)(SE)}{(G)(I)(NO.)}\right|$$

(3) Force due to Dead Load Bending Moment

This force is also a "worst case" number that assumes the flanged connection is in the center of the maximum allowed dead load span. The formula is:

$$F3 = \left|\frac{(W)(L^2)}{3(G)(NO.)}\right|$$

(4) Force due to Differential Expansion

The ASME/ANSI B31.3 Code determines that for an uninsulated joint the flanges are approximately 90 percent, and the bolts approximately 80 percent, of line temperature. These values may serve as a reference for the user. They dictate that there will be a differential expansion/contraction rate for the flanges with respect to the bolts. The formula for this force is:

$$F4 = (AB)(EB)\,[(ef)(TF - TI) - (eB)(TB - TI)]$$

For expansion, this number will be positive. For cryogenic cases (contraction), the force will be negative.

The final minimum required bolting force will be the combination of the above forces or:

FR = F1 + F2 + F3 if design temperature is above the temperature when installed

FR = F1 + F2 + F3 + |F4| if design temperature is below the temperature when installed

If F4 is positive (expansion case), it will add to the force needed to seal the joint, so it is not necessary to preset the bolts to compensate for it. If F4 is negative (contraction case), this will tend to open the joint, and therefore the minimum bolt tension is increased to compensate for this phenomenon.

The program goes on to calculate the minimum bolt tension required to seat the gasket, based on the input value of gasket seating stress.

The formula from ASME Section VIII is:

$$WM2 = \frac{(B)(\pi)(G)(Y)}{NO.}$$

L is calculated as the lesser of the two following formulas:

$$\text{L due to bending stress} = \sqrt{\frac{.8(Z)(SH)}{2(W')(I)}}$$

$$\text{L due to allowable deflection} = \sqrt[4]{\frac{EI\Delta}{13.5(W')}}$$

where

Δ is the allowable deflection in inches
Z is in inches to the third power
SH is in psi
W′ is the weight of pipe filled with water in lbs/ft
I is in inches to the fourth power
E Modulus of Elasticity in psi

The program goes on to choose the greater of FR and WM2 and derives the bolting stress at installation. Then, the maximum operating stress is calculated using the following formula:

SMAX = [(Greater of FR or WM2) + F1 + F2 + F3 + F4] / Bolt area

where F4 retains its calculated sign. Thus, if F4 is negative, the operating stress will be decreased by the contraction of the bolts. If F4 is positive, the bolt expansion will increase the stress.

The final calculations give the user the forces that will tend to open the joint during hydrotest. F1 and F3 are recalculated and summed together to give this value. For this calculation, the following changes are made:

$$P = PH = 1.5(P)\left(\frac{SC}{SH}\right)$$

W = WH = the weight of pipe filled with water

Limitations:

The program assumes an allowable dead load deflection of 1 in. None of the input data is carried over to the next analysis. The program is self-initializing after the first execution. It should be used for flanged connections only.

The program is not written to distinguish between bolts in pure tension, as is the case with hydraulic stud tensioners, and a combination of tension and shear, as is the case with torque wrenches. The user is cautioned to review paragraphs C.2 and C.3 of ANSI B1.1, Appendix C, to determine the correct stress area to input to the program.

User Instructions

Program Number TI-59-5 **Title** Flanged Connection Bolt Tensioning

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards (3 sides).			
2	Initialize program.		E	0
3	Input OD.	OD	A	OD
4	Input T.	T	A	T
5	Input SGF.	SGF	A	SGF
6	Input ID.	ID	A	ID
7	Input IT.	IT	A	IT
8	Input P.	P	A	P
9	Input I.	I	A	I
10	Input SC.	SC	A	SC
11	Input SH.	SH	A	SH
12	Input G.	G	A	G
13	Input B.	B	A	B
14	Input M.	M	A	M
15	Input Y.	Y	A	Y
16	Input eF.	eF	A	eF
17	Input TF.	TF	A	TF
18	Input eB.	eB	A	eB
19	Input TB	TB	A	TB
20	Input AB.	AB	A	AB
21	Input EB.	EB	A	EB
22	Input NO.	NO.	A	NO.
23	Input TI.	TI	A	TI
24	Execute program.		B	
				Z
				W
				L
				SE
				F1
				F2
				F3
				F4
				FR
				WM2
				SINS
				SMAX
				PH
				WH
				FH

Data Register Contents

REGI- STER	DATA	REGI- STER	DATA
[illegible]	DSZ	30	2135 "FR"
[illegible]	OD	31	433003 "WM2"
[illegible]	T	32	36243136 "SINS"
[illegible]	SGF	33	3323 "PH"
[illegible]	ID	34	43230 "WH"
[illegible]	IT	35	2123 "FH"
[illegible]	P	36	2103 "F2"
[illegible]	I	37	2104 "F3"
[illegible]	SC	38	36301344 "SMAX"
[illegible]	SH	39	3216 "OD"
[illegible]	G	40	37 "T"
11	b	41	362221 "SGF"
12	M	42	2416 "ID"
13	y	43	2437 "IT"
14	eF	44	33 "P"
15	TF	45	24 "I"
16	eB	46	3615 "SC"
17	TB	47	3623 "SH"
18	AB	48	22 "G"
19	EB	49	14 "B"
20	No.	50	30 "M"
21	TI	51	45 "Y"
22	Z	52	5421 "eF"
23	WPL oper.	53	3721 "TB"
24	WPL h.c.	54	5414 "eB"
25	L	55	3714 "TB"
26	SE	56	1314 "ab"
27	FR	57	1714 "EB"
28	FH	58	313240 "NO."
29	DSZ	59	3724 "TI"

The data in registers 30-59 is recorded on magnetic card, side 3.

Example of an expansion case where the design temperature is higher than the installed temperature

8.625	OD	Pipe outside diameter (in)
0.322	T	Pipe wall thickness (in)
0.566	SGF	Specific gravity of fluid
11.	ID	Insulation density (lbm/ft^3)
3.	IT	Insulation thickness (in)
1000.	P	Internal pressure (psig)
2.44	I	Maximum stress intensification factor
20000.	SC	Cold stress allowable (psi)
17000.	SH	Hot stress allowable (psi)
10.5	G	*Mean diameter of gasket (G dimension) (in)
1.25	B	*Effective gasket width (B dimension) (in)
3.	M	*Gasket factor
10000.	Y	*Gasket seating stress (psi)
6.25	eF	**Coefficient of thermal expansion for flanges (μin/in/°F)
150.	TF	Operating temperature of flanges (°F)
6.19	eB	**Coefficient of thermal expansion for bolts (μin/in/°F)
125.	TB	Operating temperature of bolts (°F)
0.5	AB	Tensile area of bolts (in^2)
27.9	EB	Young's modulus of elasticity for bolts (Mega psi)
12.	NO.	Number of bolts per flange
70.	TI	Installation temperature (°F)
16.809	Z	Pipe section modulus (in^3)
4.097	W	Pipe weight per inch, operating (lb/in)
367.	L	Maximum pipe span (in)
29250.	SE	Allowable stress range (psi)
27833.	F1	Force due to internal pressure (lbs)
6397.	F2	Force due to thermal bending moment (lbs)
1456.	F3	Force due to dead load bending moment (lbs)
2226.	F4	Force due to differential thermal expansion between flanges and bolts (lbs)
35686.	FR	F1 + F2 + F3 if TF>TI; F1 + F2 + F3 + F4 if TF<TI
34361.	WM2	Minimum gasket seating load (lbs)
71372.	SINS	Bolting stress at installation (psi)
147195.	SMAX	Bolting stress at operating conditions (psi)
1765.	PH	Hydrostatic test pressure (psig)
4.183	WH	Hydrostatic test weight per inch of pipe (lb/in)
50603.	FH	Force due to hydrostatic test condition (lbs)

*From ASME Section VIII, Division 1, Appendix 2
**From ASME/ANSI B31.3, Appendix C, for example

OD = 8.625"	SC = 20,000 psi	TF = 150°F
T = 0.322"	SH = 17,000 psi	eB = 6.19 μin/in/°F
SGF = 0.566	G = 10.5"	TB = 125°F
ID = 11 #/ft^3	B = 1.25	AB = 0.5"
IT = 3"	M = 3	EB = 27.9 × 10^6 PSI
P = 1000 psi	Y = 10,000 psi	No. = 12
I = 2.44	eF = 6.25 μin/in/°F	IT = 70°F

$$Z = \pi \left[\frac{(8.625)^4 - [8.625 - 2(.322)]^4}{32\ (8.625)} \right] = \underline{16.809\ \text{in}^3}$$

$$\text{Weight of pipe} = \frac{[(8.625)^2 - [8.625 - 2(.322)]^2]\pi}{4} \times 1'' \times .283\ \frac{\#}{\text{in}^3} = 2.377\ \#/\text{in}$$

$$\text{Weight of water in pipe} = \frac{[8.625 - 2(.322)]^2\pi}{4} \times \frac{62.4\ \#/\text{ft}^3}{\frac{1728\ \text{in}^3}{\text{ft}^3}} = 1.807\ \#/\text{in}$$

Weight of fluid = (0.566) (1.807) = 1.023 #/in.

$$\text{Weight of insulation} = \frac{([8.625 + 2(3)]^2 - 8.625^2)\pi}{4} \times \frac{11\ \#/\text{ft}^3}{\frac{1728\ \text{in}^3}{\text{ft}^3}} = 0.697\ \#/\text{in}$$

Operating weight of pipe per inch = 2.377 + 1.023 + .697 = $\underline{4.097\ \#/\text{in}}$

Hydrotest weight of pipe per inch = 2.377 + 1.807 = 4.184 #/in

Allowable pipe span calculations:

stress-based:

$$\sqrt{\frac{.8(16.809)(8500)}{(2.44)(4.184)12}} \times 12 = 366.543'' \approx 367''$$

deflection-based:

$$\sqrt[4]{\frac{(27.9\text{EE}6)(72.489)(1'')}{13.5\ (4.184)(12)}} \times 12 = 498.739'' \approx 499''$$

choose lesser of 2 → L = $\underline{398''}$

SA = 1.25(20,000) + .25(17,000) = $\underline{29,250\ \text{psi}}$

$$F1 = \frac{(\pi/4)(G^2)(P) + 2(b)(\pi)(G)(M)(P)}{\text{NO. of bolts}}$$

$$\frac{(\pi/4)(10.5)^2(1000) + 2(1.25)(\pi)(10.5)(3)(1000)}{12} = \underline{27833\#}$$

$$F2 = \frac{4(Z)(SE)}{(G)(T)(\text{NO. of bolts})} = \frac{4(16.809)(29250)}{(10.5)(2.44)(12)} = \underline{6397\#}$$

$$F3 = \frac{(W)(L^2)}{(3)(G)\ \text{NO. of bolts}} = \frac{(4.097)(366.543)^2}{3(10.5)(12)} = \underline{1456\#}$$

F4 = (Bolt area)(Bolt Modulus)[(eF)(TF − TI) − (eB)(TB − TI)]
where

eF = Expansion coefficient for flanges
eB = Expansion coefficient for bolts
TF = Operating temperature of flanges
TB = Operating temperature of bolts
TI = Installation temperature

$$= (0.5)(27.9)[(6.25)(150 - 70) - (6.19)(125 - 70)] = \underline{2226\ \#}$$

Because the operating temperature is above the installation temperature:

$$FR = F1 + F2 + F3 = 27833 + 6397 + 1456 = \underline{35686\#}$$

$$WM2 = \frac{(B)(G)(\pi)(Y)}{12} = \frac{(1.25)(10.5)(\pi)(10000)}{12} = \underline{34361\#}$$

Choose greater of two for maximum installed bolt stress

35686/0.5 $\underline{\text{71372 psi}}$

Maximum operating stress when installation temperature is *lower* than operating:

$$[2F1 + 2F2 + 2F3 + F4]/\text{Bolt area} = [2(27833) + 2(6397) + 2(1456) + (2226)]/0.5 = \underline{147{,}195\ \text{psi}}$$

$$\text{Hydrotest pressure} = 1.5\,P\left(\frac{SC}{SH}\right) = 1.5(1000)\left(\frac{20{,}000}{17{,}000}\right) = 1764.706 = \underline{1765\ \text{psi}}$$

$$F1\ (\text{hydrotest}) = \frac{(\pi/4)(10.5)^2(1764.706) + 2(1.25)(\pi)(10.5)(3)(1764.706)}{\text{NO. of Bolts}} = 49116\#$$

$$F3\ \text{Hydrotest} = \frac{(4.184)(366.543)^2}{(3)(10.5)(12)} = 1487\#$$

$$F4\ \text{Hydrotest} = 49116 + 1487 = \underline{50603\#}$$

Example of a contraction case where the design temperature is lower than the installed temperature

8.625	OD	Pipe outside diameter (in)
0.322	T	Pipe wall thickness (in)
0.566	SGF	Specific gravity of fluid
11.	ID	Insulation density (lbs/ft^3)
3.	IT	Insulation thickness (in)
1000.	P	Internal pressure (psig)
2.44	I	Maximum stress intensification factor
20000.	SC	Cold stress allowable (psi)
17000.	SH	Hot stress allowable (psi)
10.5	G	*Mean diameter of gasket (G dimension) (in)
1.25	B	*Effective gasket width (B dimension) (in)
3.	M	*Gasket factor
10000.	Y	*Gasket seating stress (psi)
5.5	eF	**Coefficient of thermal expansion for flanges (μin/in/°F
-150.	TF	Operating temperature of flanges (°F)
5.57	eB	**Coefficient of thermal expansion for bolts (μin/in/°F)
-125.	TB	Operating temperature of bolts (°F)
0.5	AB	Tensile area of bolts (in^2)
27.9	EB	Young's modulus of elasticity for bolts (Mega psi)
12.	NO.	Number of bolts per flange
70.	TI	Installation temperature (°F)
16.809	Z	Pipe section modulus (in^3)
4.097	W	Pipe weight per inch, operating (lb/in)
367.	L	Maximum pipe span (in)
29250.	SE	Allowable stress range (psi)
27833.	F1	Force due to internal pressure (lbs)
6397.	F2	Force due to thermal bending moment (lbs)
1456.	F3	Force due to dead load bending moment (lbs)
-1728.	F4	Force due to differential thermal expansion between flanges and bolts (lbs
37414.	FR	F1 + F2 + F3 if TF>TI; F1 + F2 + F3 + F4 if TF<TI
34361.	WM2	Minimum gasket seating load (lbs)
74827.	SINS	Bolting stress at installation (psi)
142743.	SMAX	Bolting stress at operating conditions (psi)
1765.	PH	Hydrostatic test pressure (psig)
4.183	WH	Hydrostatic test weight per inch of pipe (lb/in)
50603.	FH	Force due to hydrostatic test condition (lbs)

*From ASME Section VIII, Division 1, Appendix 2
**From ASME ANSI B31.3, Appendix C for example

Example of a case where the gasket seating load is greater than the sum of the applied loads.

8.625	OD	Pipe outside diameter (in)
0.148	T	Pipe wall thickness (in)
0.	SGF	Specific gravity of fluid
0.	ID	Insulation density (lbs/ft^3)
0.	IT	Insulation thickness (in)
150.	P	Internal pressure (psig)
2.44	I	Maximum stress intensification factor
20000.	SC	Cold stress allowable (psi)
17000.	SH	Hot stress allowable (psi)
10.5	G	*Mean diameter of gasket (G dimension) (in)
1.25	B	*Effective gasket width (B dimension) (in)
3.	M	*Gasket factor
10000.	Y	*Gasket seating stress (psi)
5.5	eF	**Coefficient of thermal expansion for flanges (μin/in/°F)
-150.	TF	Operating temperature of flanges (°F)
5.57	eB	**Coefficient of thermal expansion for bolts (μin/in/°F)
-125.	TB	Operating temperature of bolts (°F)
0.5	AB	Tensile area of bolts (in^2)
27.9	EB	Young's modulus of elasticity for bolts (Mega psi)
12.	NO.	Number of bolts per flange
70.	TI	Installation temperature (°F)
8.212	Z	Pipe section modulus (in^3)
1.115	W	Pipe weight per inch, operating (lb/in)
299.	L	Maximum pipe span (in)
29250.	SE	Allowable stress range (psi)
4175.	F1	Force due to internal pressure (lbs)
3125.	F2	Force due to thermal bending moment (lbs)
263.	F3	Force due to dead load bending moment (lbs)
-1728.	F4	Force due to differential thermal expansion between flanges and bolts (lbs)
9291.	FR	F1 + F2 + F3 if TF>TI; F1 + F2 + F3 + F4 if TF<TI
34361.	WM2	Minimum gasket seating load (lbs)
68722.	SINS	Bolting stress at installation (psi)
80393.	SMAX	Bolting stress at operating conditions (psi)
265.	FH	Hydrostatic test pressure (psig)
3.083	WH	Hydrostatic test weight per inch of pipe (lb/in)
8094.	FH	Force due to hydrostatic test condition (lbs)

*From ASME Section VIII, Division 1, Appendix 2

**From ASME ANSI B31.3, Appendix C, for example

Sample Problem

Program: TI-59-5

OD = 8.625"	eF = 6.25 μin/in/°F
T = 0.322"	TF = 150°F
SGF = 0.566	
ID = 11 #/ft^3	
IT = 3"	eB = 6.19 μin/in/°F
	TB = 125°F
P = 1000 psig	AB = 0.5 in^2
I = 2.44	EB = 27.9 EE6
SC = 20,000 psi	NO. = 12
SH = 17,000 psi	
G = 10.5"	TI = 70°F
B = 1.25"	
M = 3	
Y = 10,000 psi	

Step	Input	Key Stroke	Display	Printer		Comments
1		E	0			Initialize program. Sets pointers for the input routine.
2	8.625	A	8.625	8.625	OD	Program stores pipe OD in R01.
3	.322	A	0.322	0.322	T	Stores pipe T in R02.
4	.566	A	0.566	0.566	SGF	Stores specific gravity of fluid in R03.
5	11	A	11.	11.	ID	Stores insulation density in R04.
6	3	A	3.	3.	IT	Stores insulation thickness in R05.
7	1000	A	1000.	1000.	P	Stores internal pressure in R06.
8	2.44	A	2.44	2.44	I	Stores intensification factor in R07.
9	20000	A	20000.	20000.	SC	Stores Cold allowable stress in R08.
10	17000	A	17000.	17000.	SH	Stores Hot allowable stress in R09.
11	10.5	A	10.5	10.5	G	Stores Gasket mean diameter in R10.
12	1.25	A	1.25	1.25	B	Stores Gasket effective width in R11.
13	3	A	3.	3.	M	Stores Gasket factor in R12.
14	10000	A	10000.	10000.	Y	Stores gasket seating stress in R13.
15	6.25	A	6.25	6.25	eF	Stores thermal expansion coefficient for flange in R14.
16	150	A	150	150	TF	Stores flange temperature in R15.
17	6.19	A	6.19	6.19	eB	Stores thermal expansion coefficient for bolts in R16.
18	125	A	125	125	TB	Stores bolt temperaturre in R17.
19	.5	A	0.5	0.5	AB	Stores bolt tensile area in R18.
20	27.9	A	27.9	27.9	EB	Stores bolt modulus of elasticity in R19.
21	12	A	12	12	NO.	Stores number of bolts in R20.
22	70	A	70	70	TI	Stores installation temperature in R21.
23		B		16.809 Z 4.097 W		The program calculates the pipe section modulus, the operating

Step	Input	Key Stroke	Display	Printer		Comments
				367.	L	weight per inch, the allowable dead load span, and the stress range.
				29250.	SE	
				27833.	F1	The program calculates next all the forces that add up to the minimum required bolt load.
				6397.	F2	
				1456.	F3	
				2226.	F4	
				35686.	FR	The program sums up the total and then calculates the minimum gasket seating load for the bolts. From the greater of the two, the program calculates the installed bolting stress.
				34361.	WM2	
				71372.	SINS	
				147195.	SMAX	
				1765.	PH	Then the maximum operating stress in the bolts is calculated.
				4.183	WH	
				50603.	FH	
						The final calculation is done using the hydrotest values for pressure and weight per inch. F1 and F3 are recalculated and summed together to make the value of FH.

Coding Form

Program Number TI-59-5 **Title** Flanged Connection Bolt Tensioning

Loc	Code	Key	Comments
000	76	LBL	Input routine: Uses R01 and R29 as pointers.
001	11	A	
002	32	X:T	
003	01	1	
004	44	SUM	
005	29	29	
006	69	OP	
007	20	20	Alpha codes are stored in memory on card side 3.
008	73	RC*	
009	29	29	
010	69	OP	
011	04	04	
012	32	X:T	
013	69	OP	
014	06	06	
015	72	ST*	
016	00	00	
017	91	R/S	
018	76	LBL	Subroutine: Divides a number by the number of bolts.
019	14	D	
020	55	÷	
021	43	RCL	
022	20	20	
023	95	=	
024	92	RTN	
025	76	LBL	Prints data with alpha labels.
026	16	A'	
027	69	OP	
028	04	04	
029	32	X:T	
030	69	OP	
031	06	06	
032	92	RTN	
033	76	LBL	Subroutine: Multiplies π times B times G.
034	19	D'	
035	43	RCL	
036	11	11	
037	65	×	
038	43	RCL	
039	10	10	
040	65	×	
041	89	π	
042	54	)	
043	92	RTN	
044	76	LBL	Subroutine: Divides a number by the bolt area.
045	10	E'	
046	55	÷	
047	43	RCL	
048	18	18	
049	95	=	
050	32	X:T	
051	92	RTN	
052	76	LBL	Subroutine: Calculates F1.
053	17	B'	
054	19	D'	
055	65	[illegible]	
056	02	2	
057	65	×	
058	43	RCL	
059	12	12	

Loc	Code	Key	Comments
060	65	×	
061	43	RCL	
062	06	06	
063	85	+	
064	89	π	
065	55	÷	
066	04	4	
067	65	×	
068	43	RCL	
069	10	10	
070	33	X^2	
071	65	×	
072	43	RCL	
073	06	06	
074	54	)	
075	14	D	
076	92	RTN	
077	76	LBL	Subroutine: Calculates F3.
078	18	C'	
079	43	RCL	
080	23	23	
081	65	×	
082	43	RCL	
083	25	25	
084	33	X^2	
085	55	÷	
086	03	3	
087	55	÷	
088	43	RCL	
089	10	10	
090	14	D	
091	92	RTN	
092	76	LBL	Main program. This part calculates pipe weight per inch, water weight-per-inch, insulation weight-per-inch, and pipe section modulus.
093	12	B	
094	98	ADV	
095	43	RCL	
096	01	01	
097	33	X^2	
098	42	STO	
099	23	23	
100	94	+/-	
101	42	STO	
102	26	26	
103	33	X^2	
104	42	STO	
105	22	22	
106	43	RCL	
107	01	01	
108	75	−	
109	02	2	
110	65	×	
111	43	RCL	
112	02	02	
113	95	=	
114	33	X^2	Pipe WPI is in R23.
115	42	STO	
116	27	27	
117	94	+/-	
118	44	SUM	Water WPI is in R27.
119	23	23	

Loc	Code	Key	Comments
120	33	X^2	
121	22	INV	
122	44	SUM	Insulation WPI is in R26.
123	22	22	
124	43	RCL	
125	01	01	
126	85	+	Pipe Z is in R22.
127	02	2	
128	65	×	
129	43	RCL	
130	05	05	
131	95	=	
132	33	X^2	
133	44	SUM	
134	26	26	
135	89	π	
136	55	÷	
137	04	4	
138	95	=	
139	49	PRD	
140	23	23	
141	49	PRD	
142	26	26	
143	49	PRD	
144	27	27	
145	55	÷	
146	08	8	
147	95	=	
148	49	PRD	
149	22	22	
150	43	RCL	
151	01	01	
152	22	INV	
153	49	PRD	
154	22	22	
155	93	.	
156	02	2	
157	08	8	
158	03	3	
159	49	PRD	
160	23	23	
161	93	.	
162	00	0	
163	03	3	
164	06	6	
165	01	1	
166	01	1	
167	49	PRD	
168	27	27	
169	43	RCL	
170	04	04	
171	55	÷	
172	01	1	
173	07	7	
174	02	2	
175	08	8	
176	95	=	
177	49	PRD	
178	26	26	
179	43	RCL	

Loc	Code	Key	Comments
180	23	23	Pipe WPI is also stored in R24. Water WPI is added to R24. Fluid WPI and insulation WPI are added to R23.
181	42	STO	
182	24	24	
183	43	RCL	
184	27	27	
185	44	SUM	
186	24	24	
187	65	×	
188	43	RCL	
189	03	03	
190	85	+	
191	43	RCL	
192	26	26	
193	95	=	
194	44	SUM	
195	23	23	
196	43	RCL	L based on bending stress is calculated and put into the test register.
197	22	22	
198	65	×	
199	43	RCL	
200	09	09	
201	55	÷	
202	43	RCL	
203	24	24	
204	55	÷	
205	03	3	
206	00	0	
207	55	÷	
208	43	RCL	
209	07	07	
210	95	=	
211	34	√X	
212	32	X:T	
213	08	8	L based on 1″ deflection is calculated.
214	06	6	
215	01	1	
216	01	1	
217	01	1	
218	65	×	
219	43	RCL	
220	22	22	
221	65	×	
222	43	RCL	
223	01	01	
224	55	÷	
225	43	RCL	
226	24	24	
227	95	=	
228	34	√X	
229	34	√X	
230	22	INV	The two values of L are compared and the smaller is converted to inches and stored in R25.
231	77	GE	
232	24	CE	
233	32	X:T	
234	76	LBL	
235	24	CE	
236	65	×	
237	01	1	
238	02	2	
239	95	=	

Loc	Code	Key	Comments
240	42	STO	
241	25	25	
242	01	1	SE is calculated and stored in R26.
243	93	.	
244	02	2	
245	05	5	
246	65	×	
247	43	RCL	
248	08	08	
249	85	+	
250	93	.	
251	02	2	
252	05	5	
253	65	×	
254	43	RCL	
255	09	09	
256	95	=	
257	42	STO	
258	26	26	
259	58	FIX	Prints Z with alpha label.
260	03	03	
261	43	RCL	
262	22	22	
263	32	X:T	
264	04	4	
265	06	6	
266	00	0	
267	16	A'	
268	43	RCL	Prints W with alpha label.
269	23	23	
270	32	X:T	
271	04	4	
272	03	3	
273	00	0	
274	16	A'	
275	58	FIX	Prints L with alpha label.
276	00	00	
277	43	RCL	
278	25	25	
279	32	X:T	
280	02	2	
281	07	7	
282	16	A'	
283	43	RCL	Prints SE with alpha label.
284	26	26	
285	32	X:T	
286	03	3	
287	06	6	
288	01	1	
289	07	7	
290	16	A'	
291	98	ADV	F1 is calculated and printed and stored in R27.
292	17	B'	
293	42	STO	
294	27	27	
295	32	X:T	
296	02	2	
297	01	1	
298	00	0	
299	02	2	

Loc	Code	Key	Comments
300	[illegible]	[illegible]	
301	[illegible]		F2 is calculated and printed and summed into R27.
302	55		
303	[illegible]	[illegible]	
304	22	[illegible]	
305	55		
306	[illegible]	[illegible]	
307	[illegible]	26	
308	55	-	
309	[illegible]	[illegible]	
310	[illegible]	[illegible]	
311	55	-	
312	43	RCL	
313	07	07	
314	[illegible]	[illegible]	
315	44	SUM	
316	27	27	
317	32	X:T	
318	43	RCL	
319	[illegible]	36	
320	[illegible]	A'	
321	18	C'	F3 is calculated, printed and summed into R27.
322	44	SUM	
323	27	27	
324	32	X:T	
325	43	RCL	
326	[illegible]	[illegible]	
327	16	A'	
328	43	RCL	F4 is calculated and stored in R28.
329	21	21	
330	94	+/-	
331	44	SUM	
332	15	15	
333	44	SUM	
334	17	17	
335	43	RCL	
336	18	18	
337	65	×	
338	43	RCL	
339	19	19	
340	65	×	
341	53	(	
342	43	RCL	
343	14	14	
344	65	×	
345	43	RCL	
346	15	15	
347	75	-	
348	43	RCL	
349	16	16	
350	65	×	
351	43	RCL	
352	17	17	
353	95	=	
354	42	STO	
355	28	28	
356	32	X:T	F4 is printed.
357	43	RCL	
358	37	37	
359	85	-	

Loc	Code	Key	Comments
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	FR is printed. If F4 is less than zero, the absolute value is added to F1 + F2 + F3.
[illegible]	43	RCL	
365	28	28	
366	29	CP	
367	77	GE	
368	44	SUM	
369	50	I×I	
370	55	÷	
371	76	LBL	
372	44	SUM	
373	43	RCL	
374	27	27	
375	95	=	The total FR is stored in R29.
376	42	STO	
377	29	29	
378	32	X:T	
379	43	RCL	
380	30	30	
381	16	A'	
382	19	D'	WM2 is calculated and printed.
383	65	×	
384	43	RCL	
385	13	13	
386	14	D	
387	32	X:T	
388	43	RCL	
389	31	31	
390	16	A'	
391	32	X:T	WM2 and FR are compared. The larger is stored in R29 and is used to calculate the installation bolt stress.
392	43	RCL	
393	29	29	
394	77	GE	
395	29	CP	
396	32	X:T	
397	42	STO	
398	29	29	
399	76	LBL	
400	29	CP	
401	10	E'	
402	43	RCL	
403	32	32	
404	16	A'	
405	43	RCL	The operating stress is calculated. The greater of FR and WM2 is added to F1 + F2 + F3 + F4. F4 holds its sign.
406	28	28	
407	85	+	
408	43	RCL	
409	29	29	
410	85	+	
411	43	RCL	
412	27	27	
413	54	)	
414	10	E'	
415	43	RCL	
416	38	38	
417	16	A'	
418	98	ADV	
419	01	1	
420	93	.	The hydrotest pressure multiplier is calculated and multiplied into R06. F1 is recalculated and stored in R28.
421	05	5	
422	65	×	
423	43	RCL	
424	08	08	
425	55	÷	
426	43	RCL	
427	09	09	
428	95	=	
429	49	PRD	
430	06	06	
431	17	B'	
432	42	STO	
433	28	28	
434	43	RCL	Hydrotest WPI is put into R23. F3 is recalculated and added to R28.
435	24	24	
436	42	STO	
437	23	23	
438	18	C'	
439	44	SUM	
440	28	28	
441	43	RCL	"PH" is printed.
442	06	06	
443	32	X:T	
444	43	RCL	
445	33	33	
446	16	A'	
447	43	RCL	"WH" is printed.
448	24	24	
449	32	X:T	
450	43	RCL	
451	34	34	
452	58	FIX	
453	03	03	
454	16	A'	
455	58	FIX	"FH" is printed.
456	00	00	
457	98	ADV	
458	43	RCL	
459	28	28	
460	32	X:T	
461	43	RCL	
462	35	35	
463	16	A'	
464	76	LBL	Initialize program.
465	15	E	
466	22	INV	
467	58	FIX	
468	03	3	
469	08	8	
470	42	STO	
471	29	29	
472	25	CLR	
473	42	STO	
474	00	00	
475	91	R/S	

Pipe outside diameter (in)
Pipe wall thickness (in)
Specific gravity of fluid
Insulation density (lbs/ft^3)
Insulation thickness (in)
Internal pressure (psig)
Maximum stress intensification factor
Cold stress allowable (psi)
Hot stress allowable (psi)
*Mean diameter of gasket (G dimension) (in)
*Effective gasket width (B dimension) (in)
*Gasket factor
*Gasket seating stress (psi)
**Coefficient of thermal expansion for flanges (µin/in/°F
Operating temperature of flanges (°F)
**Coefficient of thermal expansion for bolts (µin/in/°F)
Operating temperature of bolts (°F)
Tensile area of bolts (in^2)
Young's modulus of elasticity for bolts (Mega psi)
Number of bolts per flange
Installation temperature (°F)

Pipe section modulus (in^3)
Pipe weight per inch, operating (lb/in)
Maximum pipe span (in)
Allowable stress range (psi)

Force due to internal pressure (lbs)
Force due to thermal bending moment (lbs)
Force due to dead load bending moment (lbs)
Force due to differential thermal expansion between flanges and bolts (lbs)

Fl + F2 + F3 if TF>TI; Fl + F2 + F3 + F4 if TF<TI
Minimum gasket seating load (lbs)
Bolting stress at installation (psi)
Bolting stress at operating conditions (psi)

Hydrostatic test pressure (psig)
Hydrostatic test weight per inch of pipe (lb/in)

Force due to hydrostatic test condition (lbs)

*From ASME Section VIII, Division 1, Appendix 2
**From ASME/ANSI B31.3, Appendix C, for example

Program HP-41CV-5: Flanged Connection Bolt Tensioning

Introduction:

HP-41CV-5 performs calculations to determine the minimum required bolt tensioning for flanged joints to insure a leak-free connection. The program determines the maximum applied forces that tend to open the joint based on internal pressure, thermal and dead load bending moments, and the differential expansion/contraction of the flanges and bolts. HP-41CV-5 also determines the minimum bolt load needed to seat the gasket and the maximum installed and operating bolt stresses.

Nomenclature:

Twenty-one pieces of data must be input for the analysis:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- SGF: Specific gravity of fluid
- ID: Insulation density (lb/ft^3)
- IT: Insulation thickness (in)
- P: Internal pressure (psig)
- I: Maximum stress intensification factor
- SC: Cold allowable stress (psi)
- SH: Hot allowable stress (psi)
- G: Mean diameter of gasket (G dimension) (in)
- b: Effective gasket width (b dimension) (in)
- M: Gasket factor
- Y: Gasket seating stress (psi)
- eF: Coefficient of thermal expansion for flanges (μin/in/°F)
- TF: Operating temperature of flanges (°F)
- eB: Coefficient of thermal expansion for bolts (μin/in/°F)
- TB: Operating temperperture of bolts (°F)
- AB: Stress area of bolts (sq. in)
- EB: Young's modulus of elasticity of bolts (Mega psi)
- NO.: Number of bolts per flange
- TI: Installation temperature (°F)

The data G, b, M, and Y are defined in ASME section VIII, Div. 1, Appendix 2.

The following variables are calculated by the program:

- Z: Pipe section modulus (in^3)
- L: Maximum dead load span (in)
- SE: Allowable stress range (1.25SC + .25SH) (psi)
- W: Pipe operating weight-per-inch

Method:

HP-41CV-5 calculates four distinct forces that will tend to open the flanged joint. These are due to (1) internal pressure, (2) thermal bending moment, (3) dead load bending moment, and (4) the differential expansion or contraction between the flanges and the bolts. Each of these forces are detailed below.

(1) Force due to Internal Pressure

The formula for this force is:

$$F1 = \frac{(\pi/4)(G^2)(P) + 2(b)(\pi)(G)(M)(P)}{NO.}$$

This formula is found in ASME Section VIII, Div. 1, Appendix 2. This force is positive as long as P is positive.

(2) Force due to Thermal Bending Moment

This force is also a "worst case" number that assumes that the worst bending moment allowed will occur at the flanged connection. The stress range allowable is divided by the stress intensification factor to obtain the nominal stress value. The formula is:

$$F2 = \left| \frac{4(Z)(SE)}{(G)(I)(NO.)} \right|$$

(3) Force due to Dead Load Bending Moment

This force is also a "worst case" number that assumes the flanged connection is in the center of the maximum allowed dead load span. The formula is:

$$F3 = \left| \frac{(W)(L^2)}{3(G)(NO.)} \right|$$

(4) Force due to Differential Expansion

The ASME/ANSI B31.3 Code determines that for an uninsulated joint the flanges are approximately 90 percent, and the bolts approximately 80 percent, of line temperature. These values may serve as a reference for the user. They dictate that there will be a differential expansion/contraction rate for the flanges with respect to the bolts. The formula for this force is:

$$F4 = (AB)(EB)\,[(ef)(TF - TI) - (eB)(TB - TI)]$$

For expansion, this number will be positive. For cryogenic cases (contraction), the force will be negative.

The final minimum required bolting force will be the combination of the above forces or:

$FR = F1 + F2 + F3$ if design temperature is above the temperature when installed

$FR = F1 + F2 + F3 + |F4|$ if design temperature is below the temperature when installed

If F4 is positive (expansion case), it will add to the force needed to seal the joint, so it is not necessary to preset the bolts to compensate for it. If F4 is negative (contraction case), this will tend to open the joint, and therefore the minimum bolt tension is increased to compensate for this phenomenon.

The program goes on to calculate the minimum bolt tension required to seat the gasket, based on the input value of gasket seating stress.

The formula from ASME Section VIII is:

$$WM2 = \frac{(b)(\pi)(G)(Y)}{NO.}$$

L is calculated as the lesser of the two following formulas:

$$\text{L due to bending stress} = \sqrt{\frac{.8(Z)(SH)}{.2(W')(I)}}$$

$$\text{L due to allowable deflection} = \sqrt[4]{\frac{EI\Delta}{13.5(W')}}$$

where

Δ is the allowable deflection in inches
Z is in inches to the third power
SH is in psi
W′ is the weight of pipe filled with water in lbs/ft
I is in inches to the fourth power
E is modulus of elasticity in psi

The program goes on to choose the greater of FR and WM2 and derives the bolting stress at installation. Then the maximum operating stress is calculated by the following formula:

$$\sigma oper = [(\text{Greater of FR or WM2}) + F1 + F2 + F3 + F4]/\text{Bolt area}$$

where F4 retains its calculated sign. Thus, if F4 is negative, the bolt contraction will lessen the bolt stress at operation. If F4 is positive, the bolt expansion will add to the bolt stress during operation.

The final calculations give the user the forces that will tend to open the joint during hydrotest. F1 and F3 are re-calculated and summed together to give this value. For this calculation, the following changes are made:

$$P = PH = 1.5(P)\left(\frac{SC}{SH}\right)$$

$W = WH =$ the weight of pipe filled with water

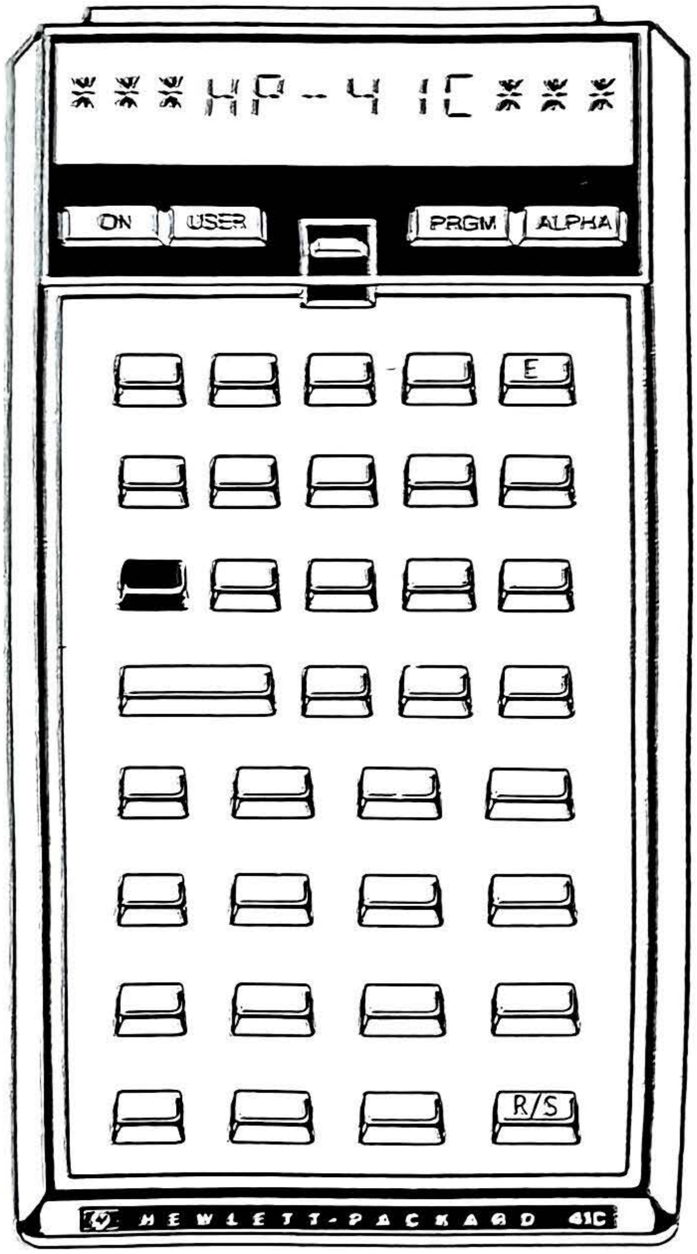
Limitations:

The program assumes an allowable dead load deflection of 1″. None of the input data is carried over to the next analysis. The program is self-initializing after the first execution. The program should be used for flanged connections only.

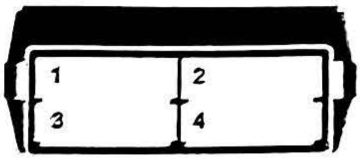
The program is not written to distinguish between bolts in pure tension, as is the case with hydraulic stud tensioners, or a combination of tension and shear, as is the case with torque wrenches. The user is cautioned to review paragraphs C.2 and C.3 of ANSI B 1.1, Appendix C, to determine the correct stress area to input to this program.

Keyboard Card Labeling

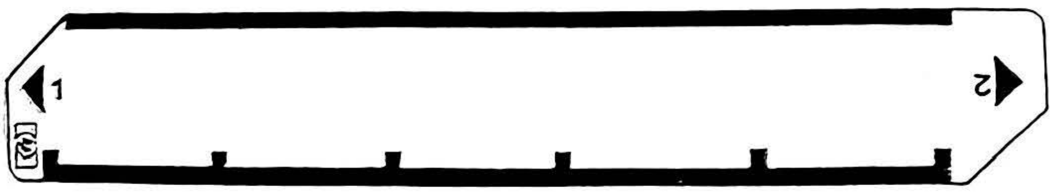
KEYBOARD



SYSTEM
CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-5 **Title** Flanged Connection Bolt Tensioning

Step	Instructions	Input	Keystroke	Display
1	Initialize program.		E	OD=
2	Input pipe size.	OD	R/S	T=
3	Input pipe wall thickness	T	R/S	SGF=
4	Input specific gravity of fluid.	SGF	R/S	ID=
5	Input insulation density.	ID	R/S	IT=
6	Input insulation thickness.	IT	R/S	P=
7	Input pipe internal pressure.	P	R/S	I=
8	Input stress intensification factor.	I	R/S	SC=
9	Input cold stress allowable.	SC	R/S	SH=
10	Input hot stress allowable.	SH	R/S	G=
11	Input mean diameter of gasket (G dimension).	G	R/S	b=
12	Input effective gasket width (b dimension).	b	R/S	M=
13	Input gasket factor.	M	R/S	Y=
14	Input gasket seating stress.	Y	R/S	eF=
15	Input coefficient of thermal expansion for flanges.	eF	R/S	TF=
16	Input operating temperature for flanges.	TF	R/S	eB=
17	Input thermal coefficient of expansion for bolts.	eB	R/S	TB=
18	Input operating temperature for bolts.	TB	R/S	AB=
19	Input stress area of bolts.	AB	R/S	EB=
20	Input Young's modulus of elasticity of bolts.	EB	R/S	NO.=
21	Input number of bolts per flange.	NO.	R/S	TI=
22	Input installation temperature.	TI	R/S	
				OUTPUT

Registers, Flags, Assignments

Program Number HP-41CV-5 Title Flanged Connection Bolt Tensioning

DATA REGISTERS

00	
01	OD
02	T
03	SGF
04	ID
05	IT
06	l
07	SC
08	SH
09	G
10	b
11	M
12	Y
13	eF
14	TF
15	eB
16	TB
17	AB
18	EB
19	NO.
20	TI
21	
22	Z
23	WPI operating
24	WPI hydrotest
25	L used
26	SE
27	Sum of F1 + F2 + F3
28	F4; Sum of F1 + F3 hydrotest
29	Sum of 2F1 + 2F2 + 2F3 + |F4| IF F4 $\geq$ 0
30	
31	
32	
33	
34	
35	
36	
37	
38	

DATA REGISTERS

39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates

ASSIGNMENTS

Label	Key	Function	Key
BS	15 (E)		

Example of a case where the operating temperature is greater than the installation temperature.

```
OD= 8.625
T= 0.322
SGF= 0.566
ID= 11.000
IT= 3.000
P= 1,000.000
I= 2.440
SC= 20,000.000
SH= 17,000.000
G= 10.500
b= 1.250
M= 3.000
Y= 10,000.000
eF= 6.250
TF= 150.000
eB= 6.190
TB= 125.000
AB= 0.500
EB= 27.900
NO.= 12.000
TI= 70.000

Z=16.809
W=4.097
L=367.
SE=29,250.

              F1.= 27,833.
               F2.= 6,397.
               F3.= 1,456.
               F4.= 2,226.

              FR= 35,686.
             WM2= 34,361.
           σinst= 71,372.
          σoper= 147,195.

Ph.t.=1,765.
Wh.t.=4.183

               FH=50,603.
```

OD = 8.625″	SC = 20,000 psi	TF = 150°F
T = 0.322″	SH = 17,000 psi	eB = 6.19 μin/in/°F
SGF = 0.566	G = 10.5″	TB = 125°F
ID = 11 #/ft^3	B = 1.25	AB = 0.5″
IT = 3″	M = 3	EB = 27.9 × 10^6 PSI
P = 1000 psi	Y = 10,000 psi	No. = 12
I = 2.44	eF = 6.25 μin/in/°F	IT = 70°F

$$Z = \pi \left[\frac{(8.625)^4 - [8.625 - 2(.322)]^4}{32\,(8.625)} \right] = \underline{16.809 \text{ in}^3}$$

$$\text{Weight of pipe} = \frac{[(8.625)^2 - [8.625 - 2(.322)]^2]\pi}{4} \times 1'' \times .283 \frac{\#}{\text{in}^3} = 2.377 \ \#/\text{in}$$

$$\text{Weight of water in pipe} = \frac{[8.625 - 2(.322)]^2\pi}{4} \times \frac{62.4 \ \#/\text{ft}^3}{\frac{1728 \text{ in}^3}{\text{ft}^3}} = 1.807 \ \#/\text{in}$$

Weight of fluid = (0.566) (1.807) = 1.023 #/in.

$$\text{Weight of insulation} = \frac{([8.625 + 2(3)]^2 - 8.625^2)\pi}{4} \times \frac{11 \ \#/\text{ft}^3}{\frac{1728 \text{ in}^3}{\text{ft}^3}} = 0.697 \ \#/\text{in}$$

Operating weight of pipe per inch = 2.377 + 1.023 + .697 = <u>4.097 #/in</u>

Hydrotest weight of pipe per inch = 2.377 + 1.807 = 4.184 #/in

Allowable pipe span calculations:

stress-based:

$$\sqrt{\frac{.8(16.809)(8500)}{(2.44)(4.184)12}} \times 12 = 366.543'' \approx 367''$$

deflection-based:

$$\sqrt[4]{\frac{(27.9E6)(72.489)(1'')}{13.5\,(4.184)(12)}} \times 12 = 498.739'' \approx 499''$$

choose lesser of 2 → L = <u>398″</u>

SA = 1.25(20,000) + .25(17,000) = <u>29,250 psi</u>

$$F1 = \frac{(\pi/4)(G^2)(P) + 2(b)(\pi)(G)(M)(P)}{\text{NO. of bolts}}$$

$$= \frac{(\pi/4)(10.5)^2(1000) + 2(1.25)(\pi)(10.5)(3)(1000)}{12} = \underline{27833\#}$$

$$F2 = \frac{4(Z)(SE)}{(G)(I)(\text{NO. of bolts})} = \frac{4(16.809)(29250)}{(10.5)(2.44)(12)} = \underline{6397\#}$$

$$F3 = \frac{(W)(L^2)}{(3)(G)\ \text{NO. of bolts}} = \frac{(4.097)(366.543)^2}{3(10.5)(12)} = \underline{1456\#}$$

F4 = (Bolt area)(Bolt Modulus)[(eF)(TF − TI) − (eB)(TB − TI)]
where

eF = Expansion coefficient for flanges
eB = Expansion coefficient for bolts
TF = Operating temperature of flanges
TB = Operating temperature of bolts
TI = Installation temperature

$$= (0.5)(27.9)[(6.25)(150 - 70) - (6.19)(125 - 70)] = \underline{2226\ \#}$$

Because the operating temperature is above the installation temperature:

$$FR = F1 + F2 + F3 = 27833 + 6397 + 1456 = \underline{35686\#}$$

$$WM2 = \frac{(B)(G)(\pi)(Y)}{12} = \frac{(1.25)(10.5)(\pi)(10000)}{12} = \underline{34361\#}$$

Choose greater of two for maximum installed bolt stress

35686/0.5 <u>71372 psi</u>

Maximum operating stress when installation temperature is *lower* than operating:

$$[2F1 + 2F2 + 2F3 + F4]/\text{Bolt area} = [2(27833) + 2(6397) + 2(1456) + (2226)]/0.5 = \underline{147{,}195\ \text{psi}}$$

$$\text{Hydrotest pressure} = 1.5\ P\left(\frac{SC}{SH}\right) = 1.5(1000)\left(\frac{20{,}000}{17{,}000}\right) = 1764.706 \simeq \underline{1765\ \text{psi}}$$

$$F1\ (\text{hydrotest}) = \frac{(\pi/4)(10.5)^2(1764.706) + 2(1.25)(\pi)(10.5)(3)(1764.706)}{\text{NO. of Bolts}} = 49116\#$$

$$F3\ \text{Hydrotest} = \frac{(4.184)(366.543)^2}{(3)(10.5)(12)} = 1487\#$$

$$F4\ \text{Hydrotest} = 49116 + 1487 = \underline{50603\#}$$

Example of a case where the operating temperature is less than the installed temperature.

```
OD= 8.625
T= 0.322
SGF= 0.566
ID= 11.000
IT= 3.000
P= 1,000.000
I= 2.440
SC= 20,000.000
SH= 17,000.000
G= 10.500
b= 1.250
M= 3.000
Y= 10,000.000
eF= 5.500
TF=-150.000
eB= 5.570
TB=-125.000
AB= 0.500
EB= 27.900
NO.= 12.000
TI= 70.000

Z=16.809
W=4.097
L=367.
SE=29,250.

            F1.= 27,833.
             F2.= 6,397.
             F3.= 1,456.
             F4.=-1,728.

             FR= 37,414.
            WM2= 34,361.
          σinst= 74,827.
          σoper= 142,743.

Ph.t.=1,765.
Wh.t.=4.183

             FH=50,603.
```

Example of a case where the gasket seating load is greater than the sum of the applied loads.

```
OD= 8.625
T= 0.148
SGF= 0.000
ID= 0.000
IT= 0.000
P= 150.000
I= 2.440
SC= 20,000.000
SH= 17,000.600
G= 10.500
b= 1.250
M= 3.000
Y= 10,000.000
eF= 5.500
TF=-150.000
eB= 5.570
TB=-125.000
AB= 0.500
EB= 27.900
NO.= 12.000
TI= 70.000

Z=8.212
W=1.115
L=298.
SE=29,250.

             F1.= 4,175.
             F2.= 3,125.
               F3.= 263.
             F4.=-1,728.

              FR= 9,291.
            WM2= 34,361.
          σinst= 68,722.
          σoper= 80,393.

Ph.t.=265.
Wh.t.=3.083

             FH=8,094.
```

Sample Problem

Program: HP-41CV-5 Title Flanged Connection Bolt Tensioning

Sample Problem (Sketch if Desired)

OD = 8.625
T = 0.322
SGF = 0.566
ID = 11 lb/ft^3
IT = 3"

P = 1000 psig
I = 2.44
SC = 20,000 psi
SH = 17,000 psi

G = 10.5"
b = 1.25"
M = 3
Y = 10,000 psi

eF = 5.50 µin/in/°F
TF = -150° F
eB = 5.57 µin/in/°F
TB = -125° F

AB = 0.5 in^2
EB = 27.9EE6
NO. = 12

TI = 70° F

Input	Function	Display	Comments
	E	OD=	Initialize program, prompt for OD.
8.625	R/S	T=	Stores OD; prompts for T.
.322	R/S	SGF=	Stores T; prompts for SGF.
.566	R/S	ID=	Stores SGF; prompts for ID.
11	R/S	IT=	Stores ID; prompts for IT.
3	R/S	P=	Stores IT; prompts for P.
1000	R/S	I=	Stores P; prompts for I.
2.44	R/S	SC=	Stores I; prompts for SC.
20000	R/S	SH=	Stores SC; prompts for SH.
17000	R/S	G=	Stores SH; prompts for G.
10.5	R/S	b=	Stores G; prompts for b.
1.25	R/S	M=	Stores b; prompts for M.
3	R/S	Y=	Stores M; prompts for Y.
10000	R/S	eF=	Stores Y; prompts for eF.
5.5	R/S	TF=	Stores eF; prompts for TF,
-150	R/S	eB=	Stores TF; prompts for eB.
5.57	R/S	TB=	Stores eB; prompts for TB.
-125	R/S	AB=	Stores TB; prompts for AB.
.5	R/S	EB=	Stores AB; prompts for EB.
27.9	R/S	NO.=	Stores EB; prompts for NO.
12	R/S	TI=	Stores NO.; prompts for TI.
70	R/S		

Input	Function	Display	Comments
		Z=16.809 W=4.097 L=367. SE= 29,250. F1.= 27,833. F2.= 6,397. F3.= 1,456. F4.= -1,728	Program stores TI and begins calculation. The values of pipe section modulus, operating weight-per-inch, minimum span, and allowable stress range are calculated and printed. The program calculates the forces due to internal pressure, thermal bending moment, dead load bending moment, and the force due to temperature gradients between flanges and bolts.
		FR= 37,414. WM2= 34,361. σinst= 74,827. σoper= 142,743.	FR is calculated and is dependent on whether or not F4 is negative or positive. WM2 is calculated and compared against FR. The greater of the two is divided by the bolt stress area to get the installation bolt stress.
		Ph.t.=1,765 Wh.t.=4.183	The operating bolt stress is also dependant on the sign of F4: It should be pointed out that the value shown for this problem would be unacceptably high.
		FH= 50,603.	The program goes on to calculate the hydrotest values of internal pressure and weight-per-inch. F1 and F3 are recalculated using these new values and are summed to give the value FH.

Coding Form

Program Number HP-41CV-5 Title Flanged Connection Bolt Tensioning

Step/Line	Key Entry	Key Code	Comments
01	♦LBL "BS"		Initialize program. Clear all registers. Clear the alpha display. Store alpha labels for input routine in R01–R20.
02	CLRG		
03	CLA		
04	"OD"		
05	ASTO 01		
06	"T"		
07	ASTO 02		
08	"SGF"		
09	ASTO 03		
10	"ID"		
11	ASTO 04		
12	"IT"		
13	ASTO 05		
14	"P"		
15	ASTO 06		
16	"I"		
17	ASTO 07		
18	"SC"		
19	ASTO 08		
20	"SH"		
21	ASTO 09		
22	"G"		
23	ASTO 10		
24	"b"		
25	ASTO 11		
26	"M"		
27	ASTO 12		
28	"Y"		
29	ASTO 13		
30	"εF"		
31	ASTO 14		
32	"TF"		
33	ASTO 15		
34	"eB"		
35	ASTO 16		
36	"TB"		
37	ASTO 17		
38	"AB"		
39	ASTO 18		
40	"EB"		
41	ASTO 19		
42	"NO."		
43	ASTO 20		
44	"TI"		
45	ASTO 21		
46	1.021		Input routine. User is prompted by the program to input each piece of data at a time. When the last piece of data has been input, the program falls into the main routine.
47	STO 00		
48	FIX 3		
49	♦LBL A		
50	CLA		
51	ARCL IND 00		
52	"⊢="		
53	SF 12		
54	PROMPT		
55	ACA		
56	CF 12		
57	ACX		
58	PRBUF		
59	STO IND 00		
60	ISG 00		
61	GTO A		
62	ADV		Main program. Pipe weight per inch, water weight per inch, insulation weight per inch, and pipe section modulus are calculated and stored. Pipe WPI is stored in R23 and R24. Water WPI is stored in R27. Insulation WPI is stored in R26. Section modulus is in R22.
63	RCL 01		
64	X↑2		
65	STO 23		
66	STO 24		
67	CHS		
68	STO 26		
69	X↑2		
70	STO 22		
71	RCL 01		
72	RCL 02		
73	2		
74	*		
75	-		
76	X↑2		
77	STO 27		
78	ST- 23		
79	ST- 24		
80	X↑2		
81	ST- 22		
82	RCL 01		
83	RCL 05		
84	2		
85	*		
86	+		
87	X↑2		
88	ST+ 26		
89	PI		
90	4		
91	/		
92	ST* 23		
93	ST* 24		
94	ST* 26		
95	ST* 27		
96	8		
97	/		Weight of pipe, fluid, and insulation is stored in R23 for an operating WPI. Weight of pipe and water is stored in R24 for a hydrotest WPI.
98	ST* 22		
99	RCL 01		
100	ST/ 22		
101	.283		
102	ST* 23		
103	ST* 24		
104	.03611		
105	ST* 27		
106	RCL 04		
107	1728		
108	/		
109	ST* 26		
110	RCL 26		
111	RCL 27		
112	RCL 03		
113	*		
114	+		
115	ST+ 23		
116	RCL 27		
117	ST+ 24		
118	.8		Allowable span length based on stress is calculated.
119	RCL 22		
120	*		
121	RCL 09		
122	*		
123	RCL 24		
124	/		
125	24		
126	/		
127	RCL 07		
128	/		
129	SQRT		
130	27.9 E6		Allowable span length based on 1" deflection is calculated.
131	RCL 22		
132	*		
133	RCL 01		
134	*		
135	RCL 24		
136	/		
137	324		
138	/		
139	SQRT		
140	SQRT		
141	X<=Y?		The two values of span length are compared. The smaller of the two is stored in R25 in inches.
142	GTO 10		
143	X<>Y		
144	♦LBL 10		
145	12		
146	*		
147	STO 25		

Step/ Line	Key Entry	Key Code	Comments
148	1.25		SE is calculated and stored in R26.
149	RCL 08		
150	*		
151	.25		
152	RCL 09		
153	*		
154	+		
155	STO 26		
156	"Z="		Program prints Z, W, L, and SE.
157	ARCL 22		
158	PRA		
159	"W="		
160	ARCL 23		
161	PRA		
162	"L="		
163	FIX 0		
164	ARCL 25		
165	PRA		
166	"SE="		
167	ARCL 26		
168	PRA		
169	ADV		F1 is calculated, stored in R27, and printed.
170	CLA		
171	XEQ B		
172	STO 27		
173	1		
174	STO 30		
175	RDN		
176	XEQ D		
177	1		F2 is calculated, summed into R27, and printed.
178	ST+ 30		
179	4		
180	RCL 22		
181	*		
182	RCL 26		
183	*		
184	RCL 10		
185	/		
186	RCL 20		
187	/		
188	RCL 07		
189	/		
190	ST+ 27		
191	XEQ D		
192	1		F3 is calculated, summed into R27, and printed.
193	ST+ 30		
194	XEQ C		
195	ST+ 27		
196	XEQ D		
197	1		F4 is calculated and stored in R28. It is then printed.
198	ST+ 30		
199	RCL 18		
200	RCL 19		
201	*		
202	RCL 15		
203	RCL 21		
204	-		
205	RCL 14		
206	*		
207	RCL 17		
208	RCL 21		
209	-		
210	RCL 16		
211	*		
212	-		
213	*		
214	STO 28		
215	XEQ D		
216	RCL 28		If F4 is negative, then $\lvert F4 \rvert$ is added to F1 + F2 + F3. If F4 is positive, it is not included.
217	X<=0?		
218	GTO 15		
219	CLX		
220	♦LBL 15		
221	ABS		
222	RCL 27		
223	+		
224	STO 29		
225	ADV		FR is printed. FR = F1 + F2 + F3 if F4 $\geq$ 0 and FR = F1 + F2 + F3 + $\lvert F4 \rvert$ if F4 $\leq$ 0.
226	"FR="		
227	SF 12		
228	ACA		
229	CF 12		
230	ACX		
231	ADV		
232	RCL 11		WM2 is calculated on a "per-bolt" basis.
233	RCL 10		
234	*		
235	RCL 13		
236	*		
237	PI		
238	*		
239	RCL 20		
240	/		
241	SF 12		WM2 is printed.
242	"WM"		
243	ACA		
244	CF 12		
245	"2"		
246	ACA		
247	SF 12		
248	"="		
249	ACA		
250	CF 12		
251	ACX		
252	ADV		
253	RCL 29		The greater of FR and WM2 is stored in R29 and is used to calculate installation stress for the bolts. This value is printed.
254	X>Y?		
255	GTO 20		
256	X<>Y		
257	STO 29		
258	♦LBL 20		
259	RCL 18		
260	/		
261	SF 12		
262	9		
263	ACCHR		
264	CF 12		
265	SF 13		
266	"INST"		
267	ACA		
268	CF 13		
269	SF 12		
270	"="		
271	ACA		
272	CF 12		
273	RDN		
274	ACX		
275	ADV		
276	RCL 27		The greater of FR or WM2 is added to F1 + F2 + F3 + F4, where F4 retains its calculated sign. This value is used to determine operating bolt stress.
277	RCL 28		
278	RCL 29		
279	+		
280	+		
281	RCL 18		
282	/		
283	SF 12		
284	9		
285	ACCHR		
286	CF 12		
287	SF 13		
288	"OPER"		
289	ACA		
290	CF 13		
291	SF 12		
292	"="		
293	ACA		
294	CF 12		

Step/Line	Key Entry	Key Code	Comments
295	RDN		
296	ACX		
297	ADV		
298	ADV		
299	1.5		Hydrotest pressure is calculated and stored in R06. Hydrotest WPI is stored in R23. F1 and F3 are recalculated and stored in R28.
300	RCL 06		
301	*		
302	RCL 08		
303	*		
304	RCL 09		
305	/		
306	STO 06		
307	RCL 24		
308	STO 23		
309	XEQ B		
310	STO 28		
311	XEQ C		
312	ST+ 28		
313	SF 12		Hydrotest value of P is printed.
314	"P"		
315	ACA		
316	CF 12		
317	SF 13		
318	"H.T."		
319	ACA		
320	CF 13		
321	SF 12		
322	"="		
323	ACA		
324	CLA		
325	ARCL 06		
326	CF 12		
327	ACA		
328	PRBUF		
329	SF 12		Hydrotest value of W is printed.
330	"W"		
331	ACA		
332	CF 12		
333	SF 13		
334	"H.T."		
335	ACA		
336	CF 13		
337	SF 12		
338	"="		
339	ACA		
340	CF 12		
341	CLA		
342	FIX 3		
343	ARCL 23		
344	FIX 3		
345	ACA		
346	PRBUF		
347	ADV		FH is printed. FH is the sum of Hydrotest F1 and F3.
348	"FH="		
349	SF 12		
350	ACA		
351	CF 12		
352	CLA		
353	FIX 0		
354	ARCL 28		
355	ACA		
356	ADV		
357	ADV		Go to initializer.
358	ADV		
359	GTO "BS"		
360	♦LBL B		Subroutine: Calculates F1.
361	PI		
362	4		
363	/		
364	RCL 10		
365	X↑2		
366	*		
367	RCL 06		
368	*		
369	2		
370	RCL 11		
371	*		
372	PI		
373	*		
374	RCL 10		
375	*		
376	RCL 12		
377	*		
378	RCL 06		
379	*		
380	+		
381	RCL 20		
382	/		
383	RTN		
384	♦LBL C		Subroutine: Calculates F3.
385	RCL 23		
386	RCL 25		
387	X↑2		
388	*		
389	3		
390	/		
391	RCL 10		
392	/		
393	RCL 20		
394	/		
395	RTN		
396	♦LBL D		
397	"F"		Subroutine: F"a" is printed, where "a" is 1, 2, 3, or 4.
398	SF 12		
399	ACA		
400	FIX 0		
401	CF 12		
402	CLA		
403	ARCL 30		
404	ACA		
405	SF 12		
406	"="		
407	ACA		
408	CF 12		
409	ACX		
410	ADV		
411	RTN		
412	.END.		

Chapter 6

Fillet Weld Sizing

Program HP-41CV-6

Introduction:

HP-41CV-6 is a program intended to aid the user in designing the size of fillet welds, the most common kind of welding used in steel design. The analysis used is based on the Line-area Method, which is discussed in Design of Welded Structures by Omer W. Blodgett. The program has nine basic weld shapes and uses dimensions, stress allowables, and applied forces and moments provided by the user. The analysis provides the maximum force (resolved) on the weld and the recommended minimum weld size.

Nomenclature:

Nine pieces of data are provided by the user:

- d: Weld dimension along the X-axis (in)
- b: Weld dimension along the Z-axis (in)
- Sa: Weld allowable stress of weld (psi)
- FX: Force along the X-axis (lb)
- FY: Force along the Y-axis (lb)
- FZ: Force along the Z-axis (lb)
- MX: Moment about the X-axis (ft-lb)
- MY: Moment about the Y-axis (ft-lb)
- MZ: Moment about the Z-axis (ft-lb)

All forces should be input with magnitude *and* sign. All dimensions and reference coordinate axes are shown in figure 6.2. The output consists of six items:

- Fa: Force (resolved) per inch at Point A (lb/in)
- Fb: Force (resolved) per inch at Point B (lb/in)
- Fc: Force (resolved) per inch at Point C (lb/in)
- Fd: Force (resolved) per inch at Point D (lb/in)
- FR: Maximum of the above forces (lb)
- t: Minimum weld throat dimension (in)

Method:

The Line-area Method assumes the weld to be a dimensionless line in the calculation of the size of the weld to be used. This method saves the designer from having to assume a weld size, calculate its area, calculate the maximum stress in the welded area, and determine if the chosen weld size is sufficient. Instead, the designer calculates the maximum force in the welded area, uses a maximum allowed stress for his welding material, and combines these with the known length of his weld to determine the weld size.

HP-41CV-6 does all of this for the designer. The forces at extreme points of the weldshape are calculated, the weld "area" is calculated, the weld allowable is input by the user, and the program calculates the recommended weld size. The resolved forces are calculated using the following four equations:

$$Fa = \left(\left(\frac{FX}{A} + \frac{MY(Cxr)}{Jw} \right)^2 + \left(\frac{FZ}{A} - \frac{MY(Czt)}{Jw} \right)^2 + \left(\frac{FY}{A} - \frac{MX}{Swxr} + \frac{MZ}{Swzt} \right)^2 \right)^{1/2}$$

$$Fb = \left(\left(\frac{FX}{A} - \frac{MY(Cxl)}{Jw} \right)^2 + \left(\frac{FZ}{A} - \frac{MY(Czt)}{Jw} \right)^2 + \left(\frac{FY}{A} + \frac{MX}{Swxl} + \frac{MZ}{Swzt} \right)^2 \right)^{1/2}$$

$$Fc = \left(\left(\frac{FX}{A} - \frac{MY(Cxl)}{Jw} \right)^2 + \left(\frac{FZ}{A} + \frac{MY(Czb)}{Jw} \right)^2 + \left(\frac{FY}{A} + \frac{MX}{Swxl} - \frac{MZ}{Swzb} \right)^2 \right)^{1/2}$$

$$Fd = \left(\left(\frac{FX}{A} + \frac{MY(Cxr)}{Jw} \right)^2 + \left(\frac{FZ}{A} + \frac{MY(Czb)}{Jw} \right)^2 + \left(\frac{FY}{A} - \frac{MX}{Swxr} - \frac{MZ}{Swzb} \right)^2 \right)^{1/2}$$

The recommended weld size is calculated using this formula:

$$t = FR/(Sa)(0.707)$$

The factor 0.707 is based on the convention that the weld area is proportional to the throat dimension divided by the square root of 2.

The terms used above are defined as follows:

Cxl: Distance from the neutral axis to the left-most part of the weldshape (in)
Cxr: Distance from the neutral axis to the right-most part of the weldshape (in)
Czt: Distance from the neutral axis to the top of the weldshape (in)
Czb: Distance from the neutral axis to the bottom of the weldshape (in)
Swzt: Section modulus of the weldshape above the neutral axis (in^2)
Swzb: Section modulus of the weldshape below the neutral axis (in^2)
Swxl: Section modulus of the weldshape to the left of the neutral axis (in^2)
Swxr: Section modulus of the weldshape to the right of the neutral axis (in^2)
Jw: Polor moment of inertia of the weldshape (in^3)
A: Weld "area" or total length of the weld (in)

The program analyzes nine specific weldshapes:

1: Two parallel equal-length welds along the X-axis
2: A 90-degree angle, from a corner down and to the right
3: A channel shape, open end facing to the right
4: A rectangle shape
5: A T shape with a single weld across the top
6: A T shape with a double weld across the top
7: An I shape with single welds across the top and bottom
8: An I shape with double welds across the top and bottom
9: A circular shape. This analysis includes an elliptically shaped weld.

The equations and the characteristics of the weldshapes are from Design of Welded Structures by Omer W. Blodgett, Section 7.4.

The chart on page 172 of this text is an enhanced version of Table 5 found in Section 7.4 of *Design of Welded Structures*, page 7. At the bottom are the coordinate axes used and the directions of b and d.

Limitations:

HP-41CV-6 will perform one or all of the weldshape analyses for any given set of input data. Once the data input routine begins, no data is carried over from the last dataset. Only English units may be used. The analysis cannot combine weldshapes. The weld size is intended for fillet welds only. The maximum resolved force is always used for the weld size, but the designer may elect to use any of the forces printed. Finally, the designer cannot choose a point to be analyzed. Only points located by the program are analyzed.

Figure 6.1 Schematic of Weldshape Dimensions

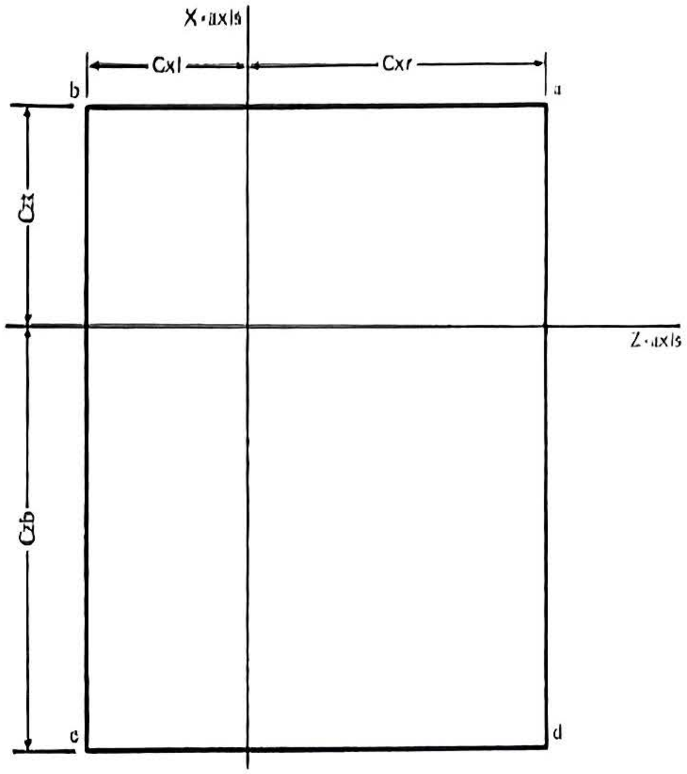
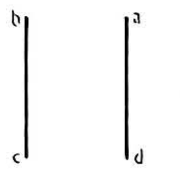
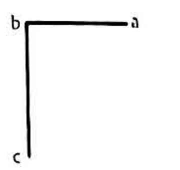
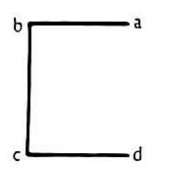
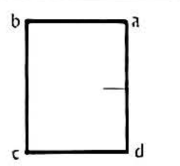
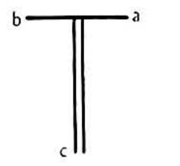
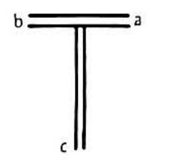
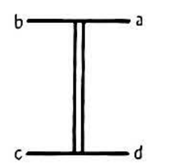
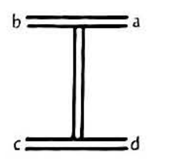
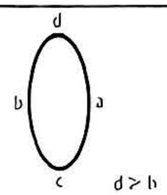
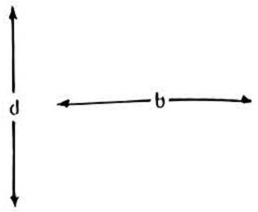
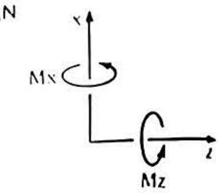


Figure 6.2 Basic Weldshapes

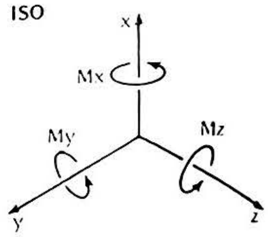
SHAPE	Cz	Cx	Swz	Swx	Jw
1. 	TOP $d/2$	LEFT $b/2$	TOP $d^2/3$	LEFT bd	$\frac{d(3b^2 + d^2)}{6}$
	BOTTOM $d/2$	RIGHT $b/2$	BOTTOM $d^2/3$	RIGHT bd	
2. 	TOP $\frac{d^2}{2(b + d)}$	LEFT $\frac{b^2}{2(d + b)}$	TOP $\frac{4bd + d^2}{6}$	LEFT $\frac{4bd + b^2}{6}$	$\frac{(b + d)^4 - 6b^2d^2}{12(b + d)}$
	BOTTOM $d - \frac{d^2}{2(b + d)}$	RIGHT $b - \frac{b^2}{2(d + b)}$	BOTTOM $\frac{d^2(4b + d)}{6(2b + d)}$	RIGHT $\frac{b^2(4d + b)}{6(2d + b)}$	
3. 	TOP $d/2$	LEFT $\frac{b^2}{2b + d}$	TOP $bd + \frac{d^2}{6}$	LEFT $\frac{2bd + b^2}{3}$	$\frac{(2b + d)^3}{12} - \frac{b^2(b + d)^2}{2b + d}$
	BOTTOM $d/2$	RIGHT $b - \frac{b^2}{2b + d}$	BOTTOM $bd + \frac{d^2}{6}$	RIGHT $\frac{b^2(2d + b)}{3(b + d)}$	
4. 	TOP $d/2$	LEFT $b/2$	TOP $bd + \frac{d^2}{3}$	LEFT $bd + \frac{b^2}{3}$	$\frac{(b + d)^3}{6}$
	BOTTOM $d/2$	RIGHT $b/2$	BOTTOM $bd + \frac{d^2}{3}$	RIGHT $db + \frac{b^2}{3}$	
5. 	TOP $\frac{d^2}{2(b + d)}$	LEFT $b/2$	TOP $\frac{2bd + d^2}{3}$	LEFT $b^2/6$	$\frac{d^3}{3}\left(\frac{2b + d}{b + 2d}\right) + \frac{b^3}{12}$
	BOTTOM $d - \frac{d^2}{2(b + d)}$	RIGHT b^2	BOTTOM $\frac{d^2(2b + d)}{3(b + d)}$	RIGHT $b^2/6$	
6. 	TOP $\frac{d^2}{2(b + d)}$	LEFT $b/2$	TOP $\frac{4bd + d^2}{3}$	LEFT $b^2/3$	$\frac{d^3(4b + d)}{6(b + d)} + \frac{b^3}{6}$
	BOTTOM $d - \frac{d^2}{2(b + d)}$	RIGHT $b/2$	BOTTOM $\frac{4bd^2 + d^3}{6b + 3d}$	RIGHT $b^2/3$	
7. 	TOP $d/2$	LEFT $b/2$	TOP $bd + \frac{d^2}{3}$	LEFT bd	$\frac{b^3 + 3bd^2 + d^3}{6}$
	BOTTOM $d/2$	RIGHT $b/2$	BOTTOM $bd + \frac{d^2}{3}$	RIGHT bd	
8. 	TOP $d/2$	LEFT $b/2$	TOP $2bd + \frac{d^2}{3}$	LEFT $2bd$	$\frac{2b^3 + 6bd^2 + d^3}{6}$
	BOTTOM $d/2$	RIGHT $b/2$	BOTTOM $2bd + \frac{d^2}{3}$	RIGHT $2bd$	
9. 	TOP $d/2$	LEFT $b/2$	TOP $\frac{\pi bd}{16}\left(3 + \frac{d}{b}\right)$	LEFT $\frac{\pi b^2}{16}\left(1 + \frac{3d}{b}\right)$	$\frac{\pi b^3}{32}\left(\frac{d^2}{b^2}\left(3 + \frac{d}{b}\right) + \left(1 + \frac{3d}{b}\right)\right)$
	BOTTOM $d/2$	RIGHT $b/2$	BOTTOM $\frac{\pi bd}{16}\left(3 + \frac{d}{b}\right)$	RIGHT $\frac{\pi b^2}{16}\left(1 + \frac{3d}{b}\right)$	



PLAN

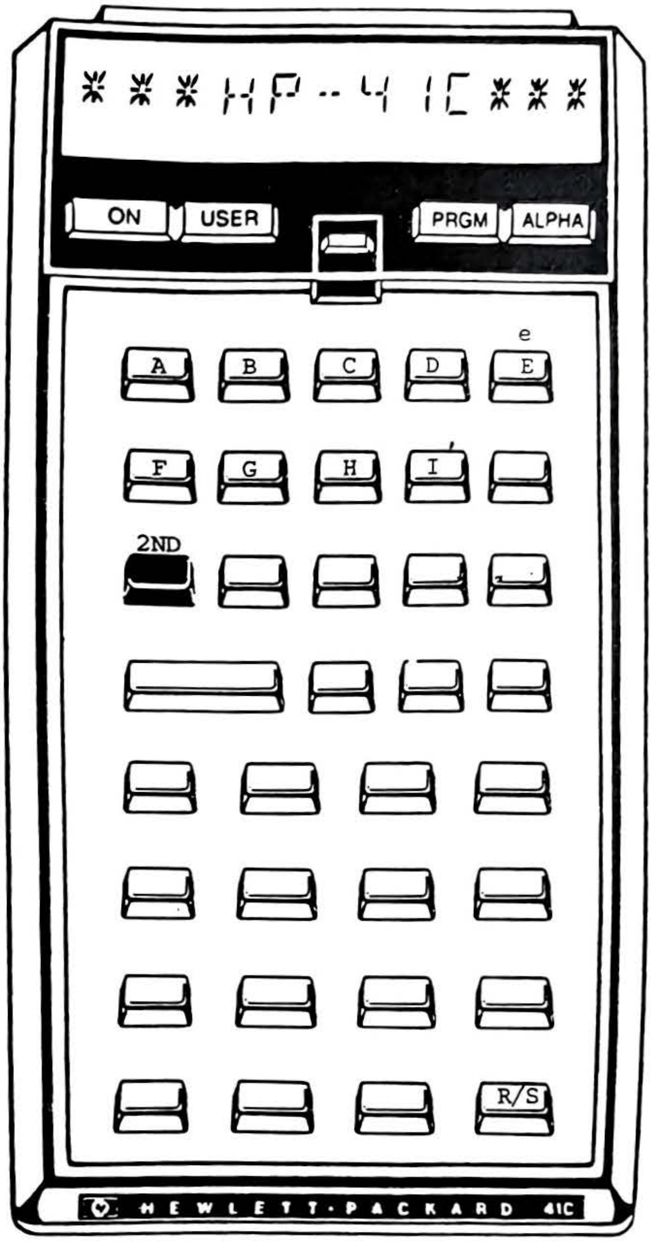


ISO

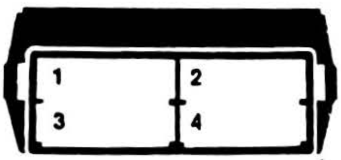


Keyboard Card Labeling

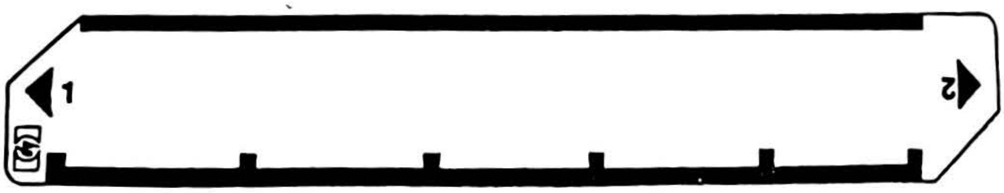
KEYBOARD



SYSTEM CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-6 **Title** Fillet Weld Sizing

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards.			
2	Initialize program.		e	d=
3	Input weld d dimension	d	R/S	b=
4	Input weld b dimension.	b	R/S	Sa=
5	Input weld allowable stress/inch (Sa).	Sa	R/S	FX=
6	Input force on weld in X-direction (FX).	FX	R/S	FY=
7 -	Input force on weld in Y-direction (FY).	FY	R/S	FZ=
8	Input force on weld in Z-direction (FZ).	FZ	R/S	MX=
9	Input moment in X-direction (MX).	MX	R/S	MY
10	Input moment in Y-direction (MY).	MY	R/S	MZ=
11	Input moment in Z-direction (MZ).	MZ	R/S	SHAPE?
12	Select weldshape to be analyzed: A= PARALLEL B= ANGLE C= CHANNEL D= RECTANGLE E= SINGLE T F= DOUBLE T G= SINGLE I H= DOUBLE I I= CIRCLE (ELLIPSE)			t

Registers, Flags, Assignments

Program Number HP-41CV-6 **Title** Fillet Weld Sizing

DATA REGISTERS

00	Pointer/counter
01	d
02	b
03	Sa
04	FX
05	FY
06	FZ
07	MX
08	MY
09	MZ
10	Aw
11	Jw
12	Swzt
13	Swzb
14	Swxl
15	Swxr
16	Czt
17	Czb
18	Cxl
19	Cxr
20	FRa
21	FRb
22	FRc
23	FRd
24	FR
25	t
26	FX/Aw
27	FY/Aw
28	Fz/Aw
29	My/Jw
30	Used
31	Used
32	
33	
34	
35	
36	
37	
38	

DATA REGISTERS

39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates
1	C	Internal changes	
2	C	Internal changes	

ASSIGNMENTS

Label	Key	Function	Key
PRL	11 (A)		
ANG	12 (B)		
CNL	13 (C)		
REC	14 (D)		
STEE	15 (E)		
DTEE	21 (F)		
SWF	22 (G)		
DWF	23 (H)		
CRCL	24 (I)		
WLD	-15 (e)		

d= 7.000
b= 5.000
Sa= 21,000.000
FX= 1,000.000
FY= 2,500.000
FZ=-500.000
MX= 1,000.000
MY=-3,000.000
MZ= 200.000

SINGLE T

Fa=2,901.204
Fb=3,286.013
Fc=1,439.587
Fd=0.000

FR= 3,286.013
t = 0.221

PARALLEL

Fa=1,000.605
Fb=1,274.901
Fc=1,201.384
Fd=1,105.529

FR= 1,274.901
t = 0.086

DOUBLE T

Fa=1,489.993
Fb=1,771.968
Fc=1,215.916
Fd=0.000

FR= 1,771.968
t = 0.119

ANGLE

Fa=2,132.915
Fb=1,147.872
Fc=2,072.966
Fd=0.000

FR= 2,132.915
t = 0.144

SINGLE I

Fa=1,482.134
Fb=1,772.239
Fc=1,704.237
Fd=1,580.793

FR= 1,772.239
t = 0.119

CHANNEL

Fa=1,100.190
Fb=902.625
Fc=879.062
Fd=1,206.222

FR= 1,206.222
t = 0.081

DOUBLE I

Fa=748.643
Fb=939.727
Fc=903.552
Fd=808.646

FR= 939.727
t = 0.063

RECTANGLE

Fa=512.678
Fb=694.330
Fc=668.793
Fd=575.851

FR= 694.330
t = 0.047

CIRCLE

Fa=585.300
Fb=839.381
Fc=772.913
Fd=748.797

FR= 839.381
t = 0.057

Sample Problem #1

SHAPE = <u>ANGLE</u>

d = 7.000"; b = 5.000"
Weld "area" = 5 + 7 = 12"
Swz (top) = [(4)(5)(7) + (7)^2] ÷ 6 = 31.500
Swz (bottom) = [(7)^2(4(5) + 7)] ÷ [6(2(5) + 7)] = 12.971
Swx (left) = [(4)(5)(7) + (5)^2] ÷ 6 = 27.500
Swx (right) = [(5)^2(4(7) + 5)] ÷ [6(2(7) + 5)] = 7.237
Jw = [5 + 7]^4 − 6(5)^2(7)^2] ÷ [12(5 + 7)] = 92.958
Czt = (7)^2 ÷ [2(5 + 7)] = 2.042"
Czb = 7 − 2.042 = 4.958"
Cxl = (5)^2 ÷ [2(5 + 7)] = 1.042"
Cxr = 5 − 1.042 = 3.958"

$$Fa = \left(\left(\frac{FX}{A} + \frac{MY(Cxr)}{Jw}\right)^2 + \left(\frac{FZ}{A} - \frac{MY(Czt)}{Jw}\right)^2 + \left(\frac{FY}{A} - \frac{MX}{Swxr} + \frac{Mz}{Swzt}\right)^2\right)^{1/2} = \left(\left[\frac{1000}{12} + \frac{(-36000)(3.958)}{92.958}\right]^2\right.$$

$$\left. + \left[\frac{(-500)}{12} - \frac{(-36000)(2.042)}{92.958}\right]^2 + \left[\frac{2500}{12} - \frac{12000}{7.237} + \frac{2400}{31.500}\right]^2\right)^{1/2} = 2132.854 \text{ \#/in}$$

$$Fb = \left(\left(\frac{FX}{A} - \frac{MY(Cx1)}{Jw}\right)^2 + \left(\frac{FZ}{A} - \frac{MY(Czt)}{Jw}\right)^2 + \left(\frac{FY}{A} + \frac{MX}{Swxl} - \frac{Mz}{Swzt}\right)^2\right)^{1/2} = \left(\left[\frac{1000}{12} - \frac{(-36{,}000)(1.042)}{92.958}\right]^2\right.$$

$$\left. + \left[\frac{(-500)}{12} - \frac{(-36000)(2.042)}{92.958}\right]^2 + \left[\frac{2500}{12} + \frac{12000}{27.500} + \frac{2400}{31.500}\right]^2\right)^{1/2} = 1148.014 \text{ \#/in}$$

$$Fc = \left(\left(\frac{FX}{A} - \frac{MY(Cxl)}{Jw}\right)^2 + \left(\frac{FZ}{A} + \frac{MY(Czb)}{Jw}\right)^2 + \left(\frac{FY}{A} + \frac{MX}{Swxl} - \frac{Mz}{Swzb}\right)^2\right)^{1/2} = \left(\left[\frac{1000}{12} - \frac{(-36{,}000)(1.042)}{92.958}\right]^2\right.$$

$$\left. + \left[\frac{(-500)}{12} + \frac{(-36{,}000)(4.958)}{92.958}\right]^2 + \left[\frac{2500}{12} + \frac{12{,}000}{27.50} - \frac{2400}{12.791}\right]^2\right)^{1/2} = 2072.306 \text{ \#/in}$$

$$Fd = \left(\left(\frac{FX}{A} + \frac{MY(Cxr)}{Jw}\right)^2 + \left(\frac{FZ}{A} + \frac{MY(Czb)}{Jw}\right)^2 + \left(\frac{FY}{A} - \frac{MX}{Swxr} - \frac{Mz}{Swzb}\right)^2\right)^{1/2} = 0$$

Fmax = 2132.854 #/in

t = 2132.854/21,000(.707) = 0.144"

Sample Problem #2

SHAPE = RECTANGLE

d = 7.000"; b = 5.000"
Weld "area" = 2(5 + 7) = 24.000"
Swz (top) = (5)(7) + $(7)^2/3$ = 51.333
Swz (bottom) = 51.333
Swx (left) = (5)(7) + $(5)^2/3$ = 43.333
Swx (right) = 43.333
Jw = $(5 + 7)^3/6$ = 288.000
Czt = 7/2 = 3.500"
Czb = 3.500"
Cxl = 5/2 = 2.500"
Cxr = 2.500"

$$Fa = \left(\left(\frac{FX}{A} + \frac{MY(Cxr)}{Jw}\right)^2 + \left(\frac{FZ}{A} - \frac{MY(Czt)}{Jw}\right)^2 + \left(\frac{FY}{A} - \frac{MX}{Swxr} + \frac{MZ}{Swzt}\right)^2\right)^{1/2} = \left(\left[\frac{1000}{24} + \frac{(-36,000)(2.5)}{288.000}\right]^2 + \left[\frac{(-500)}{24} - \frac{(-36,000)(3.5)}{288.000}\right]^2 + \left[\frac{2500}{24} - \frac{12000}{43.333} + \frac{2400}{51.333}\right]^2\right)^{1/2} = 512.678 \text{ \#/in}$$

$$Fb = \left(\left(\frac{FX}{A} - \frac{MY(Cxl)}{Jw}\right)^2 + \left(\frac{FZ}{A} - \frac{MY(Czt)}{Jw}\right)^2 + \left(\frac{FY}{A} + \frac{MX}{Swxl} + \frac{MZ}{Swzt}\right)^2\right)^{1/2} = \left(\left[\frac{1000}{24} - \frac{(-36,000)(2.5)}{288.000}\right]^2 + \left[\frac{(-500)}{24} - \frac{(-36,000)(3.5)}{288.000}\right]^2 + \left[\frac{2500}{24} + \frac{12000}{43.333} + \frac{2400}{51.333}\right]^2\right)^{1/2} = 694.332 \text{ \#/in}$$

000)]0

$$Fc = \left(\left(\frac{FX}{A} - \frac{MY(Cxl)}{Jw}\right)^2 + \left(\frac{FZ}{A} + \frac{MY(Czb)}{Jw}\right)^2 + \left(\frac{FY}{A} + \frac{MX}{Swxr} - \frac{MZ}{Swzb}\right)^2\right)^{1/2} = \left(\left[\frac{1000}{24} - \frac{(-36000)(2.5)}{288.000}\right]^2 + \left[\frac{(-500)}{24} + \frac{(-36,000)(3.5)}{288.000}\right]^2 + \left[\frac{2500}{24} + \frac{12,000}{43.333} - \frac{2400}{51.333}\right]^2\right)^{1/2} = 668.794 \text{ \#/in}$$

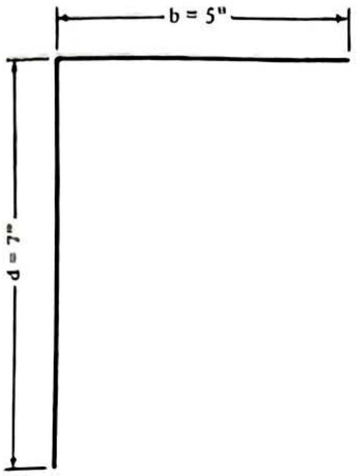
$$Fd = \left(\left(\frac{FX}{A} + \frac{MY(Cxr)}{Jw}\right)^2 + \left(\frac{FZ}{A} + \frac{MY(Czb)}{Jw}\right)^2 + \left(\frac{FY}{A} - \frac{MX}{Swxr} - \frac{MZ}{Swzb}\right)^2\right)^{1/2} = \left(\left[\frac{1000}{24} + \frac{(-36,000)(2.5)}{288.000}\right]^2 + \left[\frac{(-500)}{24} + \frac{(-36,000)(3.5)}{288.000}\right]^2 + \left[\frac{2500}{24} - \frac{12000}{43.333} - \frac{2400}{51.333}\right]^2\right)^{1/2} = 575.852 \text{ \#/in}$$

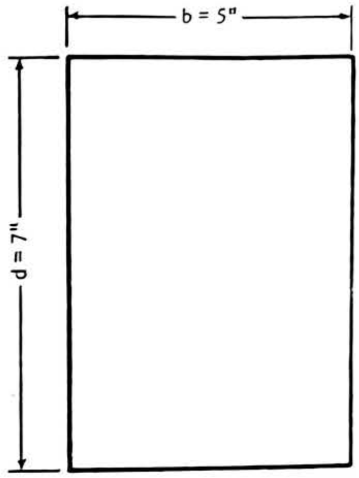
Fmax = 694.332 #/in

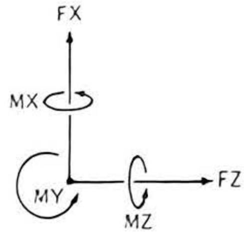
t = 694.332/21000(.707) = .047"

Program: HP-41CV-6 Title Fillet Weld Sizing

Sample Problem (Sketch if Desired)







FY Positive, out of the page.

Sa = 21,000 # per inch

FX = 1000 #	MX = 1000 ft-lb
FY = 2500 #	MY = -3000 ft-lb
FZ = -500 #	MZ = 200 ft-lb

Input	Function	Display	Comments
	e	d=	Initializes program. Prompts for the input of d.
7	R/S	b=	Stores d in R01. Prompts for b.
5	R/S	Sa=	Stores b in R02. Prompts for Sa.
21,000	R/S	FX=	Stores Sa in R03. Prompts for FX.
1000	R/S	FY=	Stores FX in R04. Prompts for FY.
2500	R/S	FZ=	Stores FY in R05. Prompts for FZ.
-500	R/S	MX=	Stores FZ in R06. Prompts for MX.
1000	R/S	MY=	Stores MX in R07. Prompts for MY.
-3000	R/S	MZ=	Stores MY in R08. Prompts for MZ.
200	R/S	SHAPE? (Printed output)	Stores MZ in R09. Prompts user for the shape of the weld to be analyzed.
	B	ANGLE	
		Fa=2,132.915 Fb=1,147.872 Fc=2,072.966 Fd=0.000 FR= 2,132.915 t= 0.144	The program shifts to the routine that calculates the inertia values and the neutral axes for the angle-shaped weld. Using the master subroutines, the forces at Points a, b, c, and d are calculated and printed. Fd is zero because there is no weld at that point. The force at a is chosen as FR and t is calculated and printed based on that number.
	D	(Printed output)	As above, the program shifts to the routines that calculate the inertias and neutral axes for a rectangular-shaped weld.

Input	Function	Display	Comments
		RECTANGLE Fa=512.678 Fb=694.330 Fc=668.793 Fd=575.851 FR=694.330 t=0.047	The same master subroutines are used to calculate the forces at all points. For a rectangle there is obviously a Point d. The force at point b is chosen as the maximum and the value of t is calculated and printed based on that value.

Coding Form

Program Number HP-41CV-6 Title Fillet Weld Sizing

Step/Line Key Entry	Key Code	Comments
01♦LBL "WLD"		Initialize program. Store alpha data for input routine. Set counter.
02 CLA		
03 CLX		
04 "d"		
05 ASTO 01		
06 "b"		
07 ASTO 02		
08 "Sa"		
09 ASTO 03		
10 "FX"		
11 ASTO 04		
12 "FY"		
13 ASTO 05		
14 "FZ"		
15 ASTO 06		
16 "MX"		
17 ASTO 07		
18 "MY"		
19 ASTO 08		
20 "MZ"		
21 ASTO 09		
22 1.009		
23 STO 00		
24 FIX 3		
25♦LBL "AA"		Input routine. Uses R00 as a pointer and a counter. Prints all input data with alpha labels.
26 CLA		
27 ARCL IND 00		
28 "⊢="		
29 PROMPT		
30 SF 12		
31 ACA		
32 CF 12		
33 ACX		
34 STO IND 00		
35 PRBUF		
36 ISG 00		
37 GTO "AA"		
38 ADV		Transforms moments from foot-lb to inch-lb.
39 SF 12		
40 12		
41 ST* 07		
42 ST* 08		
43 ST* 09		
44 "SHAPE?"		Prompts user for weldshape.
45 PROMPT		
46♦LBL "PRL"		Parallel weldshape routine.
47 "PARALLEL"		
48 PRA		
49 RCL 01		

Step/Line Key Entry	Key Code	Comments
50 2		Calculates all inertias and neutral axes for a parallel weld.
51 *		
52 STO 10		
53 RCL 01		
54 X↑2		
55 3		
56 /		
57 STO 12		
58 STO 13		
59 RCL 01		
60 RCL 02		
61 *		
62 STO 14		
63 STO 15		
64 RCL 01		
65 X↑2		
66 RCL 02		
67 X↑2		
68 3		
69 *		
70 +		
71 RCL 01		
72 *		
73 6		
74 /		
75 STO 11		
76 RCL 01		
77 2		
78 /		
79 STO 16		
80 STO 17		
81 RCL 02		
82 2		
83 /		
84 STO 18		
85 STO 19		
86 XEQ "FR"		Executive force and printout routines.
87 XEQ "PR"		
88♦LBL "ANG"		Angle-shaped weld routines.
89 "ANGLE"		
90 PRA		
91 RCL 01		
92 RCL 02		
93 +		
94 STO 10		
95 RCL 01		
96 RCL 02		
97 4		
98 *		

Step/Line Key Entry	Key Code	Comments
99 *		
100 STO 12		
101 STO 14		
102 RCL 01		
103 X↑2		
104 STO 16		
105 ST+ 12		
106 RCL 02		
107 X↑2		
108 STO 18		
109 ST+ 14		
110 4		
111 RCL 01		
112 *		
113 RCL 02		
114 +		
115 *		
116 2		
117 RCL 01		
118 *		
119 RCL 02		
120 +		
121 /		
122 STO 15		
123 4		
124 RCL 02		
125 *		
126 RCL 01		
127 +		
128 LASTX		
129 X↑2		
130 *		
131 RCL 02		
132 2		
133 *		
134 RCL 01		
135 +		
136 /		
137 STO 13		
138 6		
139 ST/ 12		
140 ST/ 13		
141 ST/ 14		
142 ST/ 15		
143 RCL 01		
144 RCL 02		
145 +		
146 X↑2		
147 X↑2		

Step/ Line	Key Entry	Key Code	Comments
148	RCL 01		
149	X↑2		
150	RCL 02		
151	X↑2		
152	*		
153	6		
154	*		
155	-		
156	12		
157	/		
158	RCL 01		
159	RCL 02		
160	+		
161	/		
162	STO 11		
163	RCL 01		
164	RCL 02		
165	+		
166	2		
167	*		
168	ST/ 16		
169	ST/ 18		
170	RCL 01		
171	RCL 16		
172	-		
173	STO 17		
174	RCL 02		
175	RCL 18		
176	-		
177	STO 19		Executive force routine.
178	XEQ "FR"		
179	0		Zero out Fd. Execute printout routine.
180	STO 23		
181	XEQ "PR"		
182	♦LBL "CNL"		Channel-shaped weld routines.
183	"CHANNEL"		
184	PRA		
185	RCL 01		
186	RCL 02		
187	2		
188	*		
189	+		
190	STO 10		
191	RCL 01		
192	RCL 02		
193	*		
194	RCL 01		
195	X↑2		
196	6		

Step/ Line	Key Entry	Key Code	Comments
197	/		
198	+		
199	STO 12		
200	STO 13		
201	2		
202	RCL 01		
203	RCL 02		
204	*		
205	*		
206	RCL 02		
207	X↑2		
208	+		
209	3		
210	/		
211	STO 14		
212	2		
213	RCL 01		
214	*		
215	RCL 02		
216	+		
217	RCL 02		
218	X↑2		
219	*		
220	3		
221	/		
222	RCL 01		
223	RCL 02		
224	+		
225	/		
226	STO 15		
227	RCL 01		
228	RCL 02		
229	+		
230	STO 26		
231	RCL 02		
232	+		
233	3		
234	Y↑X		
235	12		
236	/		
237	RCL 26		
238	X↑2		
239	RCL 02		
240	X↑2		
241	*		
242	RCL 26		
243	RCL 02		
244	+		
245	/		

Step/ Line	Key Entry	Key Code	Comments
246	-		
247	STO 11		
248	RCL 01		
249	2		
250	/		
251	STO 16		
252	STO 17		
253	RCL 02		
254	2		
255	*		
256	RCL 01		
257	+		
258	RCL 02		
259	X↑2		
260	X<>Y		
261	/		
262	STO 18		
263	RCL 02		
264	X<>Y		
265	-		
266	STO 19		
267	XEQ "FR"		Execute force and printout routines.
268	XEQ "PR"		
269	♦LBL "REC"		Rectangular shaped weld routines.
270	"RECTANGLE"		
271	PRA		
272	RCL 01		
273	RCL 02		
274	+		
275	2		
276	*		
277	STO 10		
278	RCL 01		
279	RCL 02		
280	*		
281	ENTER↑		
282	ENTER↑		
283	RCL 01		
284	X↑2		
285	3		
286	/		
287	+		
288	STO 12		
289	STO 13		
290	RDN		
291	RCL 02		
292	X↑2		
293	3		
294	/		

Step/Line	Key Entry	Key Code	Comments
295	+		
296	STO 14		
297	STO 15		
298	RCL 01		
299	RCL 02		
300	+		
301	3		
302	Y↑X		
303	6		
304	/		
305	STO 11		
306	RCL 01		
307	2		
308	/		
309	STO 16		
310	STO 17		
311	RCL 02		
312	2		
313	/		
314	STO 18		
315	STO 19		
316	XEQ "FR"		Execute force and printout routines.
317	XEQ "PR"		
318	♦LBL "STEE"		Single Tee weldshape routines.
319	"SINGLE T"		
320	PRA		
321	RCL 01		
322	2		
323	*		
324	RCL 02		
325	+		
326	STO 10		
327	RCL 01		
328	RCL 02		
329	*		
330	2		
331	*		
332	RCL 01		
333	X↑2		
334	+		
335	3		
336	/		
337	STO 12		
338	RCL 01		
339	ENTER↑		
340	*		
341	RCL 02		
342	2		
343	*		
344	RCL 01		
345	+		
346	*		
347	STO 11		
348	3		
349	/		
350	RCL 01		
351	RCL 02		
352	+		
353	/		
354	STO 13		
355	RCL 02		
356	X↑2		
357	6		
358	/		
359	STO 14		
360	STO 15		
361	RCL 11		
362	ENTER↑		
363	3		
364	/		
365	RCL 01		
366	*		
367	RCL 02		
368	RCL 01		
369	2		
370	*		
371	+		
372	/		
373	RCL 02		
374	3		
375	Y↑X		
376	12		
377	/		
378	+		
379	STO 11		
380	RCL 01		
381	X↑2		
382	RCL 01		
383	2		
384	*		
385	RCL 02		
386	+		
387	/		
388	STO 16		
389	RCL 01		
390	X<>Y		
391	-		
392	STO 17		
393	RCL 02		
394	2		
395	/		By setting Flag 1 the program will return after calculating Fa and Fb.
396	STO 18		
397	STO 19		
398	SF 01		
399	XEQ "FR"		
400	0		Calculate Fc. Mx is zeroed out at this point.
401	STO 18		
402	STO 19		
403	RCL 07		
404	STO 31		
405	0		
406	STO 07		
407	XEQ "FR2"		
408	RCL 31		Zero out Fd. Return Mx to R07. Print results.
409	STO 07		
410	0		
411	STO 23		
412	XEQ "PR"		
413	♦LBL "DTEE"		Double tee weldshape routines.
414	"DOUBLE T"		
415	PRA		
416	RCL 01		
417	RCL 02		
418	+		
419	2		
420	*		
421	STO 10		
422	RCL 01		
423	RCL 02		
424	4		
425	*		
426	*		
427	ENTER↑		
428	ENTER↑		
429	RCL 01		
430	X↑2		
431	+		
432	3		
433	/		
434	STO 12		
435	RDN		
436	RCL 01		
437	*		
438	LASTX		
439	3		
440	Y↑X		
441	+		

Step/Line	Key Entry	Key Code	Comments
442	RCL 02		
443	6		
444	*		
445	RCL 01		
446	3		
447	*		
448	+		
449	/		
450	STO 13		
451	RCL 02		
452	X↑2		
453	3		
454	/		
455	STO 14		
456	STO 15		
457	RCL 01		
458	3		
459	Y↑X		
460	RCL 02		
461	4		
462	*		
463	RCL 01		
464	+		
465	*		
466	6		
467	/		
468	RCL 01		
469	RCL 02		
470	+		
471	/		
472	RCL 02		
473	3		
474	Y↑X		
475	6		
476	/		
477	+		
478	STO 11		
479	RCL 01		
480	X↑2		
481	2		
482	/		
483	RCL 01		
484	RCL 02		
485	+		
486	/		
487	STO 16		
488	RCL 01		
489	X<>Y		
490	-		
491	STO 17		
492	RCL 02		
493	2		
494	/		Set Flag 1. Calculate Fa and Fb.
495	STO 18		
496	STO 19		
497	SF 01		
498	XEQ "FR"		
499	0		Calculate Fc.
500	STO 18		
501	STO 19		
502	RCL 07		
503	STO 31		
504	0		
505	STO 07		
506	XEQ "FR2"		
507	RCL 31		Zero out Fd. Return Mx to R07.
508	STO 07		
509	0		
510	STO 23		
511	XEQ "PR"		
512	♦LBL "SWF"		Single I weldshape routines.
513	"SINGLE I"		
514	PRA		
515	RCL 01		
516	RCL 02		
517	+		
518	2		
519	*		
520	STO 10		
521	RCL 01		
522	RCL 02		
523	*		
524	RCL 01		
525	X↑2		
526	3		
527	/		
528	+		
529	STO 12		
530	STO 13		
531	RCL 02		
532	X↑2		
533	3		
534	/		
535	STO 14		
536	STO 15		
537	RCL 02		
538	3		
539	Y↑X		
540	RCL 02		
541	RCL 01		
542	X↑2		
543	*		
544	3		
545	*		
546	+		
547	RCL 01		
548	3		
549	Y↑X		
550	+		
551	6		
552	/		
553	STO 11		
554	RCL 01		
555	2		
556	/		
557	STO 16		
558	STO 17		
559	RCL 02		
560	2		
561	/		
562	STO 18		
563	STO 19		
564	XEQ "FR"		Execute force and printout routines.
565	XEQ "PR"		
566	♦LBL "DWF"		Double I shaped weld routines.
567	"DOUBLE I"		
568	PRA		
569	RCL 01		
570	2		
571	*		
572	RCL 02		
573	4		
574	*		
575	+		
576	STO 10		
577	RCL 01		
578	RCL 02		
579	2		
580	*		
581	*		
582	RCL 01		
583	X↑2		
584	3		
585	/		
586	+		
587	STO 12		
588	STO 13		

Step/Line	Key Entry	Key Code	Comments
589	RCL 02		
590	X↑2		
591	1.5		
592	/		
593	STO 14		
594	STO 15		
595	RCL 02		
596	3		
597	Y↑X		
598	2		
599	*		
600	RCL 02		
601	RCL 01		
602	X↑2		
603	*		
604	6		
605	*		
606	+		
607	RCL 01		
608	3		
609	Y↑X		
610	+		
611	6		
612	/		
613	STO 11		
614	RCL 01		
615	2		
616	/		
617	STO 16		
618	STO 17		
619	RCL 02		
620	2		
621	/		
622	STO 18		
623	STO 19		
624	XEQ "FR"		Execute force and printout routines.
625	XEQ "PR"		
626	♦LBL "CRCL"		Circle or ellipse shaped weld routines.
627	"CIRCLE"		
628	PRA		
629	RCL 02		
630	PI		
631	*		
632	2		
633	/		
634	1		
635	RCL 01		
636	RCL 02		
637	/		
638	+		
639	*		
640	STO 10		
641	RCL 02		
642	2		
643	/		
644	X↑2		
645	PI		
646	*		
647	4		
648	/		
649	STO 14		
650	STO 15		
651	RCL 01		
652	*		
653	RCL 02		
654	/		
655	3		
656	RCL 01		
657	RCL 02		
658	/		
659	+		
660	*		
661	STO 12		
662	STO 13		
663	RCL 01		
664	2		
665	/		
666	*		
667	STO 11		
668	RCL 01		
669	3		
670	*		
671	RCL 02		
672	/		
673	1		
674	+		
675	ST* 14		
676	ST* 15		
677	RCL 14		
678	RCL 02		
679	2		
680	/		
681	*		
682	ST+ 11		
683	RCL 02		
684	2		
685	/		
686	STO 18		
687	STO 19		
688	0		
689	STO 16		
690	STO 17		
691	RCL 09		Zero out Mz at the Z-axis (points a and b). Set Flag 1. Calculate Fa and Fb.
692	STO 31		
693	0		
694	STO 09		
695	SF 01		
696	XEQ "FR"		
697	RCL 31		Return Mz to R09. Zero out Mx at point C. Calculate Fc.
698	STO 09		
699	RCL 01		
700	2		
701	/		
702	STO 16		
703	STO 17		
704	0		
705	STO 18		
706	STO 19		
707	RCL 07		
708	STO 31		
709	0		
710	STO 07		
711	XEQ "FR2"		
712	SF 02		Calculate Fd using "FR" with Flag 2 set.
713	XEQ "FR"		
714	STO 23		Return Mx to R07. Print results.
715	RCL 31		
716	STO 07		
717	XEQ "PR"		
718	♦LBL "FR"		Force Fa and Fb subroutine.
719	RCL 04		
720	STO 26		
721	RCL 05		
722	STO 27		
723	RCL 06		
724	STO 28		
725	RCL 08		
726	RCL 11		Calculate Fa.
727	/		
728	STO 29		
729	RCL 10		
730	ST/ 26		
731	ST/ 27		
732	ST/ 28		
733	RCL 26		
734	RCL 29		
735	RCL 19		

Step/Line	Key Entry	Key Code	Comments
736	*		
737	+		
738	X↑2		
739	STO 30		
740	RCL 28		
741	RCL 29		
742	RCL 16		
743	*		
744	-		
745	X↑2		
746	ST+ 30		
747	RCL 27		
748	RCL 07		
749	RCL 15		
750	/		
751	-		
752	RCL 09		
753	RCL 12		
754	/		
755	+		
756	X↑2		
757	RCL 30		
758	+		
759	SQRT		If Flag 2 is set, return *before* storing the calculated force.
760	FS?C 02		
761	RTN		
762	STO 20		Store Fa in R20.
763	RCL 26		
764	RCL 29		
765	RCL 18		
766	*		
767	-		
768	X↑2		
769	STO 30		
770	RCL 28		Calculate Fb.
771	RCL 29		
772	RCL 16		
773	*		
774	-		
775	X↑2		
776	ST+ 30		
777	RCL 27		
778	RCL 07		
779	RCL 14		
780	/		
781	+		
782	RCL 09		
783	RCL 12		
784	/		
785	+		
786	X↑2		
787	RCL 30		
788	+		
789	SQRT		
790	STO 21		Store Fb in R21.
791	FS?C 01		Return if Flag 1 is set.
792	RTN		
793	♦LBL "FR2"		Force Fc and Fd subroutine.
794	RCL 26		
795	RCL 29		
796	RCL 18		
797	*		
798	-		
799	X↑2		
800	STO 30		
801	RCL 28		
802	RCL 29		Calculate Fc.
803	RCL 17		
804	*		
805	+		
806	X↑2		
807	ST+ 30		
808	RCL 27		
809	RCL 07		
810	RCL 14		
811	/		
812	+		
813	RCL 09		
814	RCL 13		
815	/		
816	-		
817	X↑2		
818	RCL 30		
819	+		
820	SQRT		Store Fc in R22.
821	STO 22		
822	RCL 26		
823	RCL 29		Calculate Fd.
824	RCL 19		
825	*		
826	+		
827	X↑2		
828	STO 30		
829	RCL 28		
830	RCL 29		
831	RCL 17		
832	*		
833	+		
834	X↑2		
835	ST+ 30		
836	RCL 27		
837	RCL 07		
838	RCL 15		
839	/		
840	-		
841	RCL 09		
842	RCL 13		
843	/		
844	-		
845	X↑2		
846	RCL 30		
847	+		
848	SQRT		
849	STO 23		Store Fd in R23 and return.
850	RTN		
851	♦LBL "PR"		Printout subroutine. Print Fa, Fb, Fc and Fd.
852	CLA		
853	ADV		
854	CF 12		
855	"Fa="		
856	ARCL 20		
857	PRA		
858	CLA		
859	"Fb="		
860	ARCL 21		
861	PRA		
862	CLA		
863	"Fc="		
864	ARCL 22		
865	PRA		
866	CLA		
867	"Fd="		
868	ARCL 23		
869	PRA		
870	CLA		
871	ADV		
872	RCL 20		Choose greater of Fa and Fb.
873	RCL 21		
874	X>Y?		
875	GTO 11		
876	X<>Y		
877	♦LBL 11		Choose greater of last decision and Fc.
878	RCL 22		
879	X>Y?		
880	GTO 12		
881	X<>Y		
882	♦LBL 12		

Step/ Line	Key Entry	Key Code	Comments	Step/ Line	Key Entry	Key Code	Comments	Step/ Line	Key Entry	Key Code	Comments
883	RCL 23		Choose greater of Fd and last decision.								
884	X>Y?										
885	GTO 13										
886	X<>Y										
887	♦LBL 13		Print largest force as "FR". Calculate and print "τ".								
888	STO 24										
889	SF 12										
890	"FR="										
891	ACA										
892	CF 12										
893	ACX										
894	ADV										
895	RCL 03										
896	/										
897	2										
898	SQRT										
899	*										
900	STO 25										
901	SF 12										
902	SF 13										
903	"T="										
904	ACA										
905	CF 13										
906	CF 12										
907	ACX										
908	ADV										
909	ADV										
910	SF 12										
911	STOP										
912	END		STOP								

Chapter **7**

Shell Stresses From Externally Applied Loads on Welded Attachments

Program TI-59-7

Introduction:

TI-59-7 performs an analysis of the stresses in a cylindrical shell caused by external loading through a welded attachment. The source equations are from WRC-198 by Dodge, Rodabaugh, and Moore. The program will analyze a rectangular or a circular attachment for bearing loads, bending moments, shear forces, and torsional moments. The output consists of two sets of stresses: Dodge's original analysis and the modified analysis, applied to the *Primary Stress Indices* Equations from ASME Section III.

Nomenclature:

Twelve pieces of data are used by the program to perform the analysis:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- PAD: Pad thickness (in)
- LT: Rectangular attachment transverse length (in)
- LL: Rectangular attachment longitudinal length (in)
- COD: Outside diameter of circular attachment (in)
- R: Radial or axial thrust load (lb)
- TS: Transverse shear load (lb)
- LS: Longitudinal shear load (lb)
- ML: Longitudinal moment (ft-lb)
- MC: Circumferential moment (ft-lb)
- MT: Torsional moment (ft-lb)

The output consists of two sets of data:

- SR: Stress due to radial load (psi)
- SL: Stress due to longitudinal moment (psi)
- SC: Stress due to circumferential moment (psi)
- S1: Shear stress due to transverse shear load (psi)
- S2: Shear stress due to longitudinal shear load (psi)
- ST: Shear stress due to torsional moment (psi)

Each set of data has the same identifiers.

Method:

The equations used by the program are from Welding Research Council Bulletin #198, by Dodge, Rodabaugh, and Moore. While the specific equations used are listed here, it is suggested that the entire article be read for a full understanding of the method:

$C_T^* = 12.0(r/t)^{.64}(\eta)^{1.54}$ Equation 1a for rectangular analyses

$C_T^* = 18.0(r/t)^{.64}(\eta)^{1.54}$ Equation 1a for circular analyses

$C_L^* = 1.20(r/t)^{.74}(\eta)^{4.74}$ Equation 1b

$C_C^* = 1.80(r/t)^{.90}(\eta)^{3.40}$ Equation 1c

$$\eta = -(X1\cos\theta + Y1\sin\theta) - \frac{1}{Ao}(X1\sin\theta - Y1\cos\theta)^2 \quad \text{Eq.1d}$$

$X1 = Xo + \log(\beta_1)$ Equation 1e

$Y1 = Yo + \log(\beta_2)$ Equation 1f

$SR = C_T^*\,(R)/Ap$ Equation 2a

$SL = C_L^{*}(ML)/Zp$ Equation 2b

$SC = C_C^{*}(MC)/Zp$ Equation 2c

where

Ap = Metal cross sectional area of pipe (in^2)
Zp = Section modulus of pipe (in^3)
r = Pipe mean diameter (in)
t = Pipe wall thickness at attachment, including pad thickness (in)

Load	θ	Ao	Xo	Yo
R	40	2.2	0	0.05
ML	50	2.0	−0.45	−0.55
MC	40	1.8	−0.75	−0.60

$$\beta_1 = \frac{LT}{2r} \text{ for rectangular attachments}$$

$$\beta_2 = \frac{LL}{2r} \text{ for rectangular attachments}$$

$$\beta_1 = \beta_2 = \frac{COD}{2r} \text{ for thrust loading only, circular attachments}$$

$$\beta_1 = \beta_2 = \frac{COD}{2r} \times \left(1 - \frac{COD}{2r}\right) \text{ for moment loading, circular attachments}$$

$C_T = SR/(R/A_I)$ Equation 3a

$C_{L^*} = SL/(ML/Z_{IL})$ Equation 3b

$C_C = SC/(MC/Z_{IC})$ Equation 3c

$A_I = 2(LT)(LL)$ Equation 4a

(For circular attachments, $LT = LL = COD/2$)

$Z_{IL} = 4/3(LT)(LL)^2$ Equation 4b

$Z_{IC} = 4/3(LT)^2(LL)$ Equation 4c

$B_T = 2/3(C_T)$
$B_L = 2/3(C_L)$
$B_C = 2/3(C_C)$

Found on page 32, WRC-198

For rectangular attachments:

$$S1 = \frac{TS}{2(LT)t} \quad \text{Equation 10}$$

$$S2 = \frac{LS}{2(LL)t} \quad \text{Equation 11}$$

$$ST = \frac{MT}{t(LT)(LL)(1 + Lc/Ld)/2} \quad \text{Equation 12}$$

Where Ld is the greater of LT and LL and Lc is the lesser.

For circular attachments:

$$S1 = \frac{TS}{\pi(COD)(PAD + T)/2} \quad \text{Equation 10}$$

$$S2 = \frac{LS}{\pi(COD)(PAD + T)/2} \quad \text{Equation 11}$$

$$ST = \frac{MT}{\pi(COD)^2(PAD + T)/2} \quad \text{Equation 12}$$

$$SR' = B_T\left(\frac{R}{A_I}\right)$$

$$SL' = B_L\left(\frac{ML}{Z_{IL}}\right) \quad \text{From Equation 21}$$

$$SC' = B_C\left(\frac{MC}{Z_{IC}}\right)$$

The first output data set is based on Dodge's original paper, which calculated the stress based on the section modulus of the pipe. The program uses all of Equations 1 and 2 and Equations 10, 11, and 12 for this data set. The second data set is based on the contributions of Rodabaugh and Moore, who adjusted the stresses so that they are based on the section modulus of the welded lug. This second set was intended to be added to the *Primary Stress Indices* outlined in ASME, Section III, Paragraph NB 3652. This data set uses all of Equations 3 and 4 to adjust the stresses from data set 1 to get the stresses found in Equation 21. Equations 10, 11, and 12 are also part of the second data set.

The following is a comparison of the two data sets with an identical analysis performed by a mainframe computer using the equations found in Welding Research Council Bulletin #107:

RECTANGULAR ATTACHMENT

SR	SL	SC	S1	S2	ST	
613	17,527	22,230	167	167	***	WRC-107
558	22,459	36,591	167	167	4000	WRC-198 Dataset 1
372	14,972	24,395	167	167	4000	WRC-198 Dataset 2

CIRCULAR ATTACHMENT

SR	SL	SC	S1	S2	ST	
303	20,257	29,728	198	198	1898	WRC-107
638	31,513	58,084	198	198	1898	WRC-198 Dataset 1
125	21,009	38,721	198	198	1898	WRC-198 Dataset 2

The output of WRC-198 for SR, SL, and SC represent the maximum membrane and bending stress in the welded attachment.

Limitations:

The analyst must be careful which data set is to be used. Dataset 1 is intended to be a stand-alone stress value for the pipe at the point of attachment, not regarding the internal pressure stresses. Dataset 2 is intended to be added to all other stresses calculated for the point of attachment by independent means and then compared with the allowables, as presented in Paragraph NB3652 of ASME Section III.

Each execution of the program must include a complete set of input data. No data are carried over to the next analysis, although the program finishes each analysis by initializing the next. Although the authors of WRC-198 suggest that odd-shaped attachments should be analyzed by calculating equivalent shear areas and moments of inertia, it has been this author's experience that using outside dimensions with Dataset 1 is sufficient.

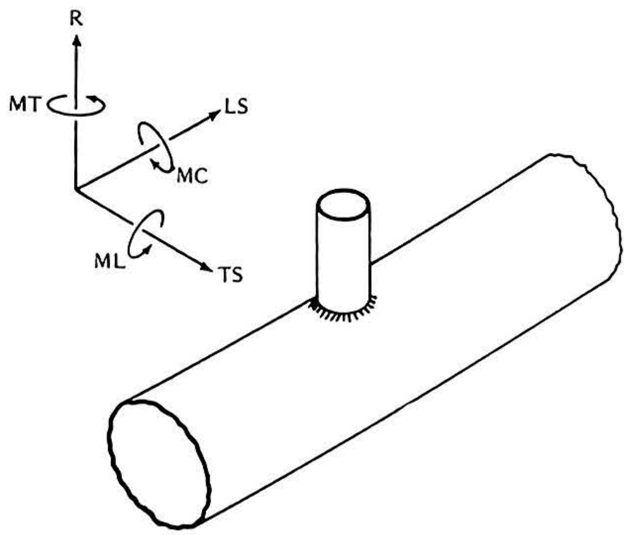
The authors of WRC-198 suggest certain size limitations for the welded attachments. They are:

$$COD/OD \leq 0.3 \text{ for circular attachments.}$$

$$\left(\frac{\beta_1}{0.3}\right)^2 + \left(\frac{\beta_2}{1.2}\right)^2 \leq 1.0 \text{ for rectangular attachments.}$$

The following is a sketch defining the various loading conditions.

Figure 7.1 Various Loading Conditions



User Instructions

Program Number TI-59-7 **Title** Shell Stresses

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards (3).		CLR	1, 2, and 3
2	Initialize program.		E	0
3	Input OD.	OD	A	OD
4	Input T.	T	A	T
5	Input PAD.	PAD	A	PAD
6	Input LT (zero for circular analysis).	LT	A	LT
7	Input LL (zero for circular analysis).	LL	A	LL
8	Input COD (zero for rectangular analysis).	COD	A	COD
9	Input R.	R	A	R
10	Input TS.	TS	A	TS
11	Input LS.	LS	A	LS
12	Input ML.	ML	A	ML
13	Input MC.	MC	A	MC
14	Input MT.	MT	A	MT
15	Execute program:			
	For circular analysis		B	0
	For rectangular analysis		C	0

Data Register Contents

REGISTER	DATA	REGISTER	DATA
00	IND	30	log (β_2); Y1
01	IND	31	log (β_1); X1
02	IND	32	log (β_2); Y1
03	IND	33	3216
04	OD	34	37
05	T	35	331316
06	PAD	36	2737
07	LT	37	2727
08	LL	38	153216
09	COD	39	35
10	R	40	3736
11	TS	41	2736
12	LS	42	3027
13	ML	43	3015 DATA STORED ON
14	MC	44	3037 MAGNETIC CARD
15	MT	45	0 (side 3)
16	Ap	46	-0.45
17	Zp-0.75	47	-0.75
18		48	0.05
19	Larger of 1/LT & 1/LL	49	-0.55
20	γ	50	-0.60
21	SR	51	40
22	SL	52	50
23	SC	53	40
24	S1	54	2.2
25	S2	55	2.0
26	ST	56	1.8
27	log (β_1); X1	57	1.54
28	log (β_2); Y1	58	4.74
29	log (β_1); X1	59	3600

This is an example of a rectangular attachment.

12.75	OD	Pipe outside diameter (in)
0.375	T	Pipe wall thickness (in)
0.25	PAD	Pad thickness (in)
3.5	LT	Rectangular attachment transverse length (in)
2.	LL	Rectangular attachment longitudinal length (in)
0.	COD	Outside diameter of circular attachment (in)
100.	R	Radial or axial thrust load (lb)
250.	TS	Transverse shear load (lb)
300.	LS	Longitudinal shear load (lb)
100.	ML	Longitudinal moment (ft-lb)
200.	MC	Circumferential moment (ft-lb)
300.	MT	Torsional moment (ft-lb)
291.	SR	Stress due to radial load (psi) (Eq. 2a)
2007.	SL	Stress due to longitudinal moment (psi) (Eq. 2b)
6394.	SC	Stress due to circumferential moment (psi) (Eq. 2c)
57.	S1	Transverse shear stress (psi) (Eq. 10)
120.	S2	Longitudinal shear stress (psi) (Eq. 11)
1047.	ST	Torsional moment shear stress (psi) (Eq. 12)
194.	SR	Stress due to radial load (psi) (Eq. 21)
1338.	SL	Stress due to longitudinal moment (psi) (Eq. 21)
4263.	SC	Stress due to circumferential moment (psi) (Eq. 21)
57.	S1	Transverse shear stress (psi) (Eq. 10)
120.	S2	Longitudinal shear stress (psi) (Eq. 11)
1047.	ST	Torsional moment shear stress (Eq. 12)

For rectangular attachments, the value COD should be zero.
For circular attachments, the values LT and LL should be zero.

RECTANGULAR ANALYSIS

OD = 12.75″
T = 0.375″
PAD = 0.25″
LT = 3.5″
LL = 2.0″

R = 100 lb
TS = 250 lb
LS = 300 lb
ML = 100 ft-lb
MC = 200 ft-lb
MT = 300 ft-lb

Ap = (12.75−0.375)(0.375)PI = 14.5790 in^2
Zp = $(12.75)^4 - (12.00)^4$ (PI)/(OD)/32 = 43.8173 in^3
r = (12.75 − 0.375)/2 = 6.1875 in
β_1 = 3.5/(2)/6.1875 = 0.2828
β_2 = 2.0/(2)/6.1875 = 0.1616
X1 = 0 + log(.2828) = −0.5485
Y1 = 0.05 + log(.1616) = −0.7415
η = −((−.5485)(cos40) + (−.7415)(sin40))
minus 1/2.2((−.5485)(sin40) − (−.7415)(cos40))^2
= 0.8758
C_T* = 12(6.1875/.625)$^{.64}$ (.8758)$^{1.54}$ = 42.4318
SR = 100(42.4318)/(14.5790) = <u>291.0473</u>

X1 = −0.45 + log(.2828) = −0.9985
Y1 = −0.55 + log(.1616) = −1.3416
η = −((−.9985)(cos50) + (−1.3416)(sin50))
minus 1/2.0((−.9985)(sin50) − (−1.3416)(cos50))^2
= 1.6648

C_L* = 1.2(6.1875/.625)$^{.74}$(1.6648)$^{4.74}$ = 73.3172
SL = 1200(73.3172)/43.8173 = <u>2007.8968</u>

X1 = −0.75 + log(.2828) = −1.2985
Y1 = −0.60 + log(.1616) = −1.3916
η = −((−1.2985)(cos40) + (−1.3916)(sin40))
minus 1/1.8((−1.2985)(sin40) − (−1.3916)(cos40))^2
= 1.8595
C_C* = 1.8(6.1875/.625)$^{.90}$ (1.8595)$^{3.40}$ = 116.7534
SC = 2400(116.7534)/43.8173 = <u>6395.2397</u>
S1 = 250/(2)/(3.5)/(.625) = <u>57.1429</u>
S2 = 300/(2)/(2.0)/(.625) = <u>120.0000</u>
ST = 3600/((3.5)(2.0)(.625)(1 − (2.0/3.5))/2) = 1047.2727

A_1 = 2(3.5)(2.0) = 14.0000
Z_{1L} = 4/3(3.5)(2.0)^2 = 18.6667
Z_{1C} = 4/3(3.5)^2(2.0) = 32.6667
C_T = 291.0473/(100/14.0000) = 40.7466
C_L = 2007.8968/(1200/18.6667) = 31.2340
C_C = 6395.2397/(2400/32.6667) = 87.0464
B_T = 2/3(40.7466) = 27.1644
B_L = 2/3(31.2340) = 20.8227
B_C = 2/3(87.0464) = 58.0309
SR′ = 27.1644(100)/14.0000 = <u>194.0314</u>
SL′ = 20.8227(1200)/18.6667 = <u>1338.5998</u>
SC′ = 58.0309(2400)/32.6667 = <u>4263.4903</u>

Shell Stresses from External Loads on Welded Attachments: WRC-198

This is an example of a circular attachment.

8.625	OD	Pipe outside diameter (in)
0.322	T	Pipe wall thickness (in)
0.	PAD	Pad thickness (in)
0.	LT	Rectangular attachment transverse length (in)
0.	LL	Rectangular attachment longitudinal length (in)
2.5	COD	Outside diameter of circular attachment (in)
100.	R	Radial or axial thrust load (lb)
250.	TS	Transverse shear load (lb)
300.	LS	Longitudinal shear load (lb)
100.	ML	Longitudinal moment (ft-lb)
200.	MC	Circumferential moment (ft-lb)
300.	MT	Torsional moment (ft-lb)
638.	SR	Stress due to radial load (psi) (Eq. 2a)
6303.	SL	Stress due to longitudinal moment (psi) (Eq. 2b)
23234.	SC	Stress due to circumferential moment (psi) (Eq. 2c)
198.	S1	Transverse shear stress (psi) (Eq. 10)
237.	S2	Longitudinal shear stress (psi) (Eq. 11)
1139.	ST	Torsional moment shear stress (psi) (Eq. 12)
425.	SR	Stress due to radial load (psi) (Eq. 21)
4202.	SL	Stress due to longitudinal moment (psi) (Eq. 21)
15489.	SC	Stress due to circumferential moment (psi) (Eq. 21)
198.	S1	Transverse shear stress (psi) (Eq. 10)
237.	S2	Longitudinal shear stress (psi) (Eq. 11)
1139.	ST	Torsional moment shear stress (Eq. 12)

For rectangular attachments, the value COD should be zero.
For circular attachments, the values LT and LL should be zero.

Sample Problem

Program: TI-59-7

OD = 12.75"
T = 0.375"
PAD = 0.25"
LT = 3.5"
LL = 2.0"
R = 100 lb
TS = 250 lb
LS = 300 lb
ML = 100 ft-lb
MC = 200 ft-lb
MT = 300 ft-lb

Step	Input	Key Stroke	Display	Printer		Comments
1		E	0			Initializes program. Loads pointer registers for input.
2	12.75	A	12.75	12.75	OD	Stores OD in R04, prints.
3	.375	A	0.375	0.375	T	Stores T in R05, prints.
4	.25	A	0.25	0.25	PAD	Stores PAD in R06, prints.
5	3.5	A	3.5	3.5	LT	Stores LT in R07, prints.
6	2	A	2.	2.	LL	Stores LL in R08, prints.
7	0	A	0.	0.	COD	Stores zero in R09, prints.
8	100	A	100.	100.	R	Stores R in R10, prints.
9	250	A	250.	250.	TS	Stores TS in R11, prints.
10	300	A	300.	300.	LS	Stores LS in R12, prints.
11	100	A	100.	100.	ML	Stores ML in R13, prints.
12	200	A	200.	200.	MC	Stores MC in R14, prints.
13	300	A	300.	300.	MT	Stores MT in R15, prints.
14		C	0.			
				291.	SR	Sums the pad thickness and
				2007.	SL	pipe thickness into one register,
				6394.	SC	R06.
				57.	S1	Calculates the shear areas for both
				120.	S2	shear forces and the torsional
				1047.	ST	moment. Stores them in R24, R25, and R26. These will later become
				194.	SR	the shear stresses.
				1338.	SL	Calculates the values of β_1 and β_2
				4263.	SC	and stores them in R27 through
				57.	S1	R32. These will later become the
				120.	S2	X1 and Y1 values. The multiplier
				1047.	ST	for the radial or axial thrust load is put into the test register. The program shifts to the main equation solver.

Step	Input	Key Stroke	Display	Printer	Comments
					The values of X1 and Y1 are calculated by adding the constants in memory to the calculated values of β_1 and β_2. The pipe metal area and section modulus are calculated and stored in R16 and R17, respectively. One at a time, the stress values for radial load, longitudinal moment, and circumferential moment are calculated, using the calculated values of X1 and Y1, and the constants stored in memory. Then the shear stresses are calculated. The first printout is performed. Then the stress values for SR, SL, and SC are adjusted to agree with Equation 21 of WRC-198. Then the second printout is performed. The program then reinitializes, and stops.

Coding Form

Program Number TI-59-7 **Title** Shell Stresses

Loc	Code	Key	Comments
000	76	LBL	Initialize program. Set pointers.
001	15	E	
002	04	4	
003	42	STO	
004	00	00	
005	03	3	
006	03	3	
007	42	STO	
008	01	01	
009	25	CLR	
010	91	R/S	
011	76	LBL	Input routine (includes B′). Uses R00 and R01 as pointers.
012	11	A	
013	72	ST*	
014	00	00	
015	73	RC*	
016	01	01	
017	69	OP	
018	04	04	
019	69	OP	
020	21	21	
021	76	LBL	Prints data with preset alpha labels.
022	17	B'	
023	73	RC*	
024	00	00	
025	69	OP	
026	06	06	
027	69	OP	
028	20	20	
029	92	RTN	
030	76	LBL	Sets alpha labels for output data.
031	19	D'	
032	85	+	
033	43	RCL	
034	59	59	
035	95	=	
036	69	OP	
037	04	04	
038	17	B'	
039	92	RTN	
040	76	LBL	Calculates X_1 and Y_1 per WRC-198 for all cases.
041	10	E'	
042	73	RC*	
043	00	00	
044	74	SM*	
045	01	01	
046	69	OP	
047	20	20	
048	69	OP	
049	21	21	
050	97	DSZ	
051	02	02	
052	10	E'	
053	92	RTN	
054	76	LBL	Calculates η per WRC-198. Uses R00, R01, R02, and R03 as pointers.
055	16	A'	
056	73	RC*	
057	00	00	
058	65	×	
059	73	RC*	

Loc	Code	Key	Comments
060	01	01	
061	39	COS	
062	85	+	
063	73	RC*	
064	02	02	
065	65	×	
066	73	RC*	
067	01	01	
068	38	SIN	
069	54	)	
070	94	+/-	
071	75	-	
072	53	(	
073	73	RC*	
074	00	00	
075	65	×	
076	73	RC*	
077	01	01	
078	38	SIN	
079	75	-	
080	73	RC*	
081	02	02	
082	65	×	
083	73	RC*	
084	01	01	
085	39	COS	
086	54	)	
087	33	X²	
088	55	÷	
089	73	RC*	
090	03	03	
091	95	=	
092	69	OP	
093	20	20	
094	69	OP	
095	21	21	
096	69	OP	
097	22	22	
098	69	OP	
099	23	23	
100	92	RTN	
101	76	LBL	Main header for circular analysis.
102	12	B	
103	43	RCL	
104	05	05	
105	44	SUM	
106	06	06	
107	43	RCL	
108	09	09	
109	35	1/X	
110	42	STO	
111	24	24	This section calculates the shear areas. Area for transverse shear is in R24. Longitudinal shear area is in R25. Torsional moment shear area is in
112	42	STO	
113	25	25	
114	42	STO	
115	26	26	
116	49	PRD	
117	26	26	
118	89	π	
119	65	×	

Loc	Code	Key	Comments
120	43	RCL	R26. *All areas are stored in reciprocal.*
121	06	06	
122	55	÷	
123	02	2	
124	95	=	
125	35	1/X	
126	49	PRD	
127	24	24	
128	49	PRD	
129	25	25	
130	49	PRD	
131	26	26	
132	43	RCL	Calculates β_1 and β_2 for thrust loads. Stores (OD-t) in R20. $\beta = \beta_1 = \beta_2$
133	09	09	
134	55	÷	
135	53	(	
136	43	RCL	
137	04	04	
138	75	-	
139	43	RCL	
140	05	05	
141	54	)	
142	42	STO	
143	20	20	
144	95	=	
145	42	STO	
146	01	01	
147	28	LOG	Stores log β in R27 and R30. Logs for β_1 and β_2 for moment loads are calculated and stored in R28, R29, R30, and R31. $\beta = \beta_1 = \beta_2$
148	42	STO	
149	27	27	
150	42	STO	
151	30	30	
152	01	1	
153	75	-	
154	43	RCL	
155	01	01	
156	54	)	
157	65	×	
158	43	RCL	
159	01	01	
160	95	=	
161	28	LOG	
162	42	STO	
163	28	28	
164	42	STO	
165	29	29	
166	42	STO	
167	31	31	
168	42	STO	
169	32	32	
170	01	1	CT multiplier is put in test register.
171	08	8	
172	32	X⇌T	
173	61	GTO	
174	18	C'	
175	76	LBL	Main control for rectangular analysis.
176	13	C	
177	43	RCL	
178	05	05	
179	44	SUM	

Loc	Code	Key	Comments
180	06	06	
181	43	RCL	This section calculates the shear areas. Transverse shear area is stored in R24. Longitudinal shear area is stored in R25. Torsional moment shear area is stored in R26. *All areas are stored in reciprocal.*
182	07	07	
183	35	1/X	
184	42	STO	
185	24	24	
186	42	STO	
187	26	26	
188	32	X⇌T	
189	43	RCL	
190	08	08	
191	35	1/X	
192	42	STO	
193	25	25	
194	49	PRD	
195	26	26	
196	22	INV	
197	77	GE	
198	02	02	
199	01	01	
200	32	X⇌T	
201	55	÷	
202	32	X⇌T	
203	85	+	
204	01	1	
205	54	)	
206	55	÷	
207	02	2	
208	95	=	
209	35	1/X	
210	49	PRD	
211	26	26	
212	43	RCL	
213	06	06	
214	35	1/X	
215	49	PRD	
216	26	26	
217	55	÷	
218	02	2	
219	95	=	
220	49	PRD	
221	24	24	
222	49	PRD	
223	25	25	
224	43	RCL	(OD − t) is stored in R20.
225	07	07	
226	55	÷	
227	53	(	
228	43	RCL	
229	04	04	
230	75	−	
231	43	RCL	
232	05	05	
233	54	)	
234	42	STO	
235	20	20	
236	95	=	
237	28	LOG	
238	42	STO	
239	27	27	

Loc	Code	Key	Comments
240	42	STO	Logs for β_1 and β_2 are stored in memory. Log β_1 is stored in R27, R28, and R29. Log β_2 is stored in R30, R31, and R32.
241	28	28	
242	42	STO	
243	29	29	
244	43	RCL	
245	08	08	
246	55	÷	
247	43	RCL	
248	20	20	
249	95	=	
250	28	LOG	
251	42	STO	
252	30	30	
253	42	STO	
254	31	31	
255	42	STO	
256	32	32	
257	01	1	CT multiplier put in test register.
258	02	2	
259	32	X⇌T	
260	76	LBL	Main program. Pointers are set for calculation of X_1 and Y_1.
261	18	C'	
262	04	4	
263	05	5	
264	42	STO	
265	00	00	
266	02	2	
267	07	7	
268	42	STO	
269	01	01	
270	06	6	
271	42	STO	
272	02	02	
273	10	E'	
274	43	RCL	γ is calculated and stored in R20.
275	20	20	
276	55	÷	
277	02	2	
278	55	÷	
279	43	RCL	
280	06	06	
281	95	=	
282	42	STO	
283	20	20	
284	01	1	Moments are converted to in-lb.
285	02	2	
286	49	PRD	
287	13	13	
288	49	PRD	
289	14	14	
290	49	PRD	
291	15	15	
292	43	RCL	Pipe metal area and section modulus are calculated. Ap is stored in R16. Zp is stored in R17.
293	04	04	
294	42	STO	
295	16	16	
296	33	X^2	
297	33	X^2	
298	42	STO	
299	17	17	

Loc	Code	Key	Comments
300	43	RCL	
301	05	05	
302	22	INV	
303	44	SUM	
304	16	16	
305	49	PRD	
306	16	16	
307	65	×	
308	02	2	
309	75	−	
310	43	RCL	
311	04	04	
312	95	=	
313	33	X^2	
314	33	X^2	
315	94	+/−	
316	44	SUM	
317	17	17	
318	89	π	
319	49	PRD	
320	16	16	
321	49	PRD	
322	17	17	
323	43	RCL	
324	04	04	
325	65	×	
326	03	3	
327	02	2	
328	95	=	
329	35	1/X	
330	49	PRD	
331	17	17	
332	02	2	Sets pointers for calculation of η.
333	07	7	
334	42	STO	
335	00	00	
336	05	5	
337	01	1	
338	42	STO	
339	01	01	
340	03	3	
341	00	0	
342	42	STO	
343	02	02	
344	05	5	
345	04	4	
346	42	STO	
347	03	03	
348	16	A'	Calculates stress due to radial load. Stores SR in R21. (Eq. 2a)
349	45	YX	
350	43	RCL	
351	57	57	
352	65	×	
353	43	RCL	
354	20	20	
355	45	YX	
356	93	.	
357	06	6	
358	04	4	
359	65	×	

Loc	Code	Key	Comments
360	32	X:T	
361	65	×	
362	43	RCL	
363	10	10	
364	55	÷	
365	43	RCL	
366	16	16	
367	95	=	
368	42	STO	
369	21	21	
370	16	A'	Calculates stress due to longitudinal moment loading. Stores SL in R22. (Eq. 2b)
371	45	Y^X	
372	43	RCL	
373	58	58	
374	65	×	
375	43	RCL	
376	20	20	
377	45	YX	
378	93	.	
379	07	7	
380	04	4	
381	65	×	
382	01	1	
383	93	.	
384	02	2	
385	65	×	
386	43	RCL	
387	13	13	
388	55	÷	
389	43	RCL	
390	17	17	
391	95	=	
392	42	STO	
393	22	22	
394	16	A'	Calculates stress due to circumferential moment loading. Stores SC in R23. (Eq. 2c)
395	45	YX	
396	03	3	
397	93	.	
398	04	4	
399	65	×	
400	43	RCL	
401	20	20	
402	45	YX	
403	93	.	
404	09	9	
405	65	×	
406	43	RCL	
407	56	56	
408	65	×	
409	43	RCL	
410	14	14	
411	55	÷	
412	43	RCL	
413	17	17	
414	95	=	
415	42	STO	
416	23	23	
417	43	RCL	
418	11	11	
419	49	PRD	
420	24	24	Calculates all shear stresses. S1 is in R24, S2 is in R25, ST is stored in R26.
421	43	RCL	
422	12	12	
423	49	PRD	
424	25	25	
425	43	RCL	
426	15	15	
427	49	PRD	
428	26	26	
429	58	FIX	Prints output data.
430	00	00	
431	98	ADV	
432	76	LBL	
433	14	D	
434	02	2	
435	01	1	
436	42	STO	
437	00	00	
438	03	3	
439	05	5	
440	19	D'	
441	02	2	
442	07	7	
443	19	D'	
444	01	1	
445	05	5	
446	19	D'	
447	02	2	
448	19	D'	
449	03	3	
450	19	D'	
451	03	3	
452	07	7	
453	19	D'	
454	87	IFF	Checks output status.
455	01	01	
456	47	CMS	
457	02	2	Adjusts SR, SL, and SC to NB 3650 level and returns to printing routine. (Eq. 21)
458	55	÷	
459	03	3	
460	95	=	
461	49	PRD	
462	21	21	
463	49	PRD	
464	22	22	
465	49	PRD	
466	23	23	
467	86	STF	
468	01	01	
469	98	ADV	
470	61	GTO	
471	14	D	
472	76	LBL	Reset flags and go to initializing routine.
473	47	CMS	
474	22	INV	
475	58	FIX	
476	98	ADV	
477	98	ADV	
478	98	ADV	
479	81	RST	

Shell Stresses from External Loads on Welded Attachments: WRC-198

Pipe outside diameter (in)
Pipe wall thickness (in)
Pad thickness (in)
Rectangular attachment transverse length (in)
Rectangular attachment longitudinal length (in)
Outside diameter of circular attachment (in)
Radial or axial thrust load (lb)
Transverse shear load (lb)
Longitudinal shear load (lb)
Longitudinal moment (ft-lb)
Circumferential moment (ft-lb)
Torsional moment (ft-lb)

Stress due to radial load (psi) (Eq. 2a)
Stress due to longitudinal moment (psi) (Eq. 2b)
Stress due to circumferential moment (psi) (Eq. 2c)
Transverse shear stress (psi) (Eq. 10)
Longitudinal shear stress (psi) (Eq. 11)
Torsional moment shear stress (psi) (Eq. 12)

Stress due to radial load (psi) (Eq. 21)
Stress due to longitudinal moment (psi) (Eq. 21)
Stress due to circumferential moment (psi) (Eq. 21)
Transverse shear stress (psi) (Eq. 10)
Longitudinal shear stress (psi) (Eq. 11)
Torsional moment shear stress (Eq. 12)

For rectangular attachments, the value COD should be zero.
For circular attachments, the values LT and LL should be zero.

Program HP-41CV-7: Shell Stresses From Externally Applied Loads on Welded Attachments

Introduction

HP-41CV-7 performs an analysis of the stresses in a cylindrical shell caused by external loading through a welded attachment. The source equations are from WRC-198 by Dodge, Rodabaugh and Moore. The program will analyse a rectangular or a circular attachment for bearing loads, bending moments, shear forces and torsional moments. The output consists of two sets of stresses, Dodge's original analysis, and the modified analysis, applied to the *Primary Stress Indices* Equations from ASME Section III.

Nomenclature:

There are 12 pieces of data that are used by the program to perform the analysis. They are:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- PAD: Pad thickness (in)
- LT: Rectangular attachment transverse length (in)
- LL: Rectangular attachment longitudinal length (in)
- COD: Circular attachment outside diameter (in)
- R: Radial or axial thrust load (lb)
- ST: Transverse shear load (lb)
- SL: Longitudinal shear load (lb)
- ML: Longitudinal moment (ft-lb)
- MC: Circumferential moment (ft-lb)
- MT: Torsional moment (ft-lb)

The output consists of two sets of data:

- σr: Stress due to radial load (psi)
- σl: Stress due to longitudinal moment (psi)
- σc: Stress due to circumferential moment (psi)
- τts: Shear stress due to transverse shear load (psi)
- τls: Shear stress due to longitudinal shear load (psi)
- τt: Shear stress due to torsional moment (psi)

Each set of data has the same identifiers.

Method:

The equations used by the program are from Welding Research Council Bulletin #198, by Dodge, Rodabaugh and Moore. While the specific equations used are listed here, it is suggested that the entire article be read for a full understanding of the method:

$C_T^* = 12.0(r/t)^{.64}(\eta)^{1.54}$ Equation 1a for rectangular analyses

$C_T^* = 18.0(r/t)^{.64}(\eta)^{1.54}$ Equation 1a for circular analyses

$C_L^* = 1.20(r/t)^{.74}(\eta)^{4.74}$ Equation 1b

$C_C^* = 1.80(r/t)^{.90}(\eta)^{3.40}$ Equation 1c

$$\eta = -(X1\cos\theta + Y1\sin\theta) - \frac{1}{Ao}(X1\sin\theta - Y1\cos\theta)^2 \quad \text{Eq. 1d}$$

$X1 = Xo + \log(\beta_1)$ Equation 1e

$Y1 = Yo + \log(\beta_2)$ Equation 1f

$\sigma r = C_T^*(R)/Ap$ Equation 2a

$\sigma l = C_L^*(ML)/Zp$ Equation 2b

$\sigma c = C_C^*(MC)/Zp$ Equation 2c

where

- Ap = Metal cross sectional area of pipe (in^2)
- Zp = Section modulus of pipe (in^3)
- r = Pipe mean diameter (in)
- t = Pipe wall thickness at attachment, including pad thickness (in)

Load	θ	Ao	Xo	Yo
R	40	2.2	0	0.05
ML	50	2.0	−0.45	−0.55
MC	40	1.8	−0.75	−0.60

$$\beta_1 = \frac{LT}{2r} \text{ for rectangular attachments}$$

$$\beta_2 = \frac{LL}{2r} \text{ for rectangular attachments}$$

$$\beta_1 = \beta_2 = \frac{COD}{2r} \text{ for thrust loading only, circular attachments}$$

$$\beta_1 = \beta_2 = \frac{COD}{2r} \times \left(1 - \frac{COD}{2r}\right) \text{ for moment loading, circular attachments}$$

$C_T = \sigma r/(R/A_1)$ Equation 3a

$C_L = \sigma l/(ML/Z_{1L})$ Equation 3b

$C_C = \sigma c/(MC/Z_{1C})$ Equation 3c

$A_1 = 2(LT)(LL)$ Equation 4a

(For circular attachments, $LT = LL = COD/2$)

$Z_{1L} = 4/3(LT)(LL)^2$ Equation 4b

$Z_{1C} = 4/3(LT)^2(LL)$ Equation 4c

$$\left.\begin{aligned} B_T &= 2/3(C_T) \\ B_L &= 2/3(C_L) \\ B_C &= 2/3(C_C) \end{aligned}\right\}$$ Found on page 32, WRC-198

For rectangular attachments:

$$\tau st = \frac{TS}{2(LT)t} \quad \text{Equation 10}$$

$$\tau ls = \frac{LS}{2(LL)t} \quad \text{Equation 11}$$

$$\tau t = \frac{MT}{t(LT)(LL)(1 + Lc/Ld)/2} \quad \text{Equation 12}$$

Where Ld is the greater of LT and LL and Lc is the lesser.

For circular attachments:

$$\tau ts = \frac{TS}{\pi(COD)(PAD + T)/2} \quad \text{Equation 10}$$

$$\tau ls = \frac{LS}{\pi(COD)(PAD + T)/2} \quad \text{Equation 11}$$

$$\tau t = \frac{MT}{\pi(COD)^2(PAD + T)/2} \quad \text{Equation 12}$$

$$\sigma r' = BT\left(\frac{R}{A_1}\right)$$

$$\sigma l' = BL\left(\frac{ML}{Z_{1L}}\right) \quad \text{From Equation 21}$$

$$\sigma C' = BC\left(\frac{MC}{Z_{1C}}\right)$$

The first output data set is based on Dodge's original paper, which calculated the stress based on the section modulus of the pipe. The program uses all of Equations 1 and 2 and Equations 10, 11, and 12 for this data set. The second data set is based on the contributions of Rodabaugh and Moore, who adjusted the stresses so that they are based on the section modulus of the welded lug. This second set was intended to be added to the *Primary Stress Indices* outlined in ASME Section III, Paragraph NB 3652. This data set uses all of Equations 3 and 4 to adjust the stresses from Dataset 1 to get the stresses found in Equation 21. Equations 10, 11, and 12 are also part of the second data set.

The following is a comparison of the two data sets with an identical analysis performed by a mainframe computer using the equations found in Welding Research Council Bulletin #107:

RECTANGULAR ATTACHMENT

σr	σl	σc	τts	τls	τt	
613	17,527	22,230	167	167	***	WRC-107
558	22,459	36,591	167	167	4000	WRC-198 Dataset 1
372	14,972	24,395	167	167	4000	WRC-198 Dataset 2

CIRCULAR ATTACHMENTS

σr	σl	σc	τts	τls	τt	
583	20,257	29,728	198	198	1898	WRC-107
638	31,513	58,084	198	198	1898	WRC-198 Dataset 1
425	21,009	38,721	198	198	1898	WRC-198 Dataset 2

The output of WRC-198 for σr, σ1, and σc represent the maximum membrane and bending stress in the welded attachment.

Limitations:

The analyst must be careful which data set is to be used. Dataset 1 is intended to be a stand-alone stress value for the pipe at the point of attachment, not regarding the internal pressure stresses. Dataset 2 is intended to be added to all other stresses calculated for the point of attachment by independent means and then compared with the allowables, as presented in Paragraph NB3652 of ASME Section III.

Each execution of the program must include a complete set of input data. No data are carried over to the next analysis, and the program does *not* initialize itself for the next analysis. Although the authors of

WRC-198 suggest that odd-shaped attachments should be analyzed by calculating equivalent shear areas and moments of inertia, it has been this author's experience that using outside dimensions with Dataset 1 is sufficient.

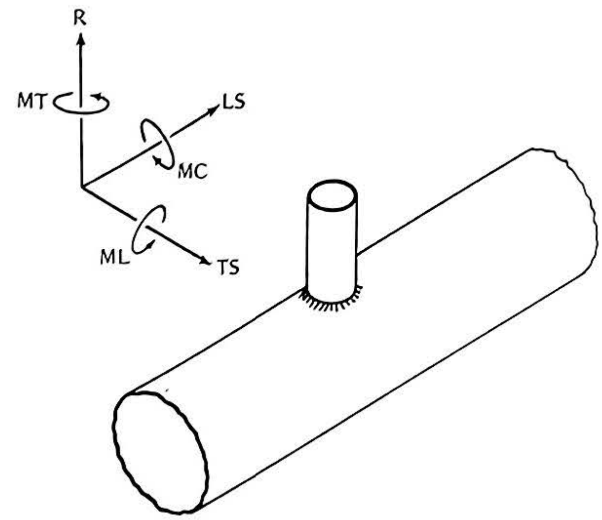
The authors of WRC-198 suggest certain size limitations for the welded attachments. They are:

COD/OD ≤ 0.3 for circular attachments.

$$\left(\frac{\beta_1}{0.3}\right)^2 + \left(\frac{\beta_2}{1.2}\right)^2 \leq 1.0 \text{ For rectangular attachments.}$$

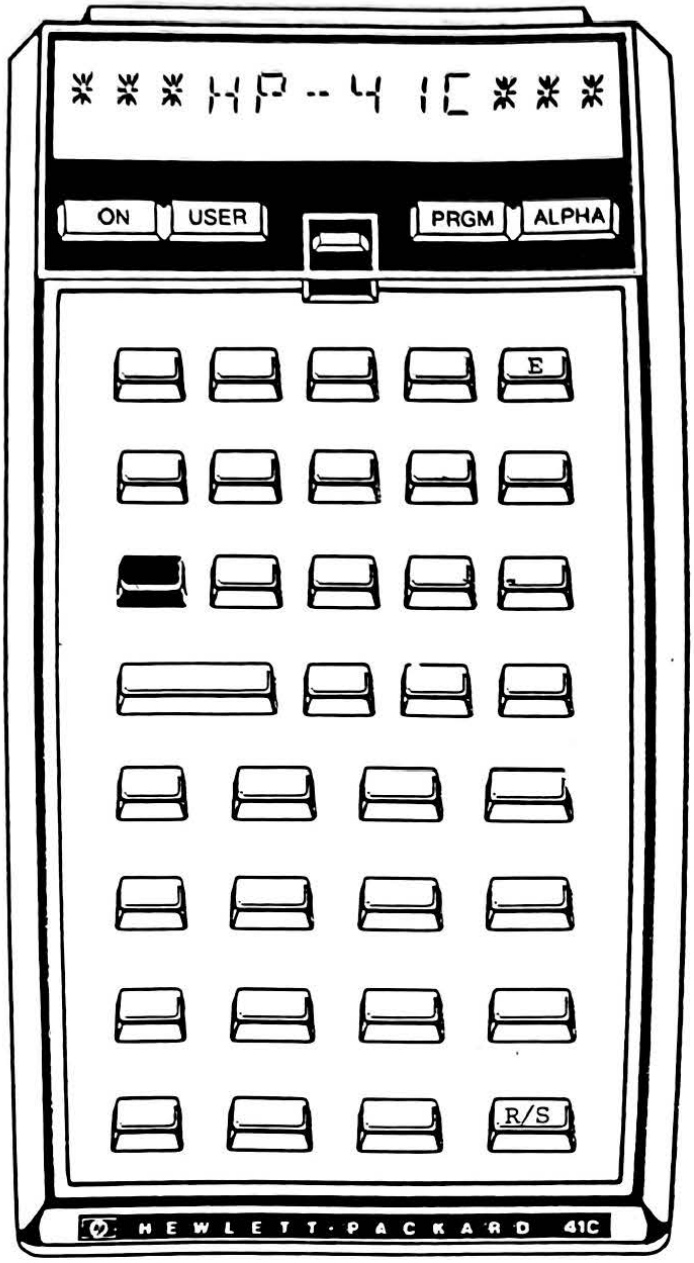
The following is a sketch, defining the various loading conditions.

Figure 7.2 Various Loading Conditions

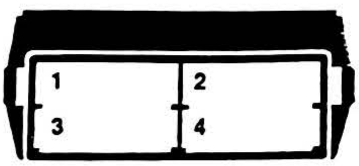


Keyboard Card Labeling

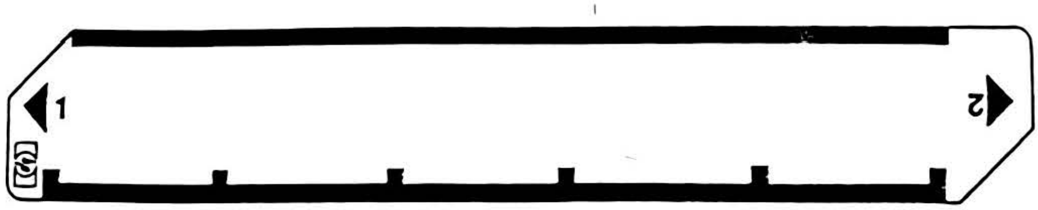
KEYBOARD



SYSTEM
CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-7 **Title** Shell Stresses

Step	Instructions	Input	Keystroke	Display
	Circular Analysis			
1	Initialize Program.		E	OD=
2	Input OD.	OD	R/S	T=
3	Input T.	T	R/S	PD=
4	Input PD.	PD	R/S	LT=
5	Input zero.	0	R/S	LL=
6	Input zero.	0	R/S	COD=
7	Input COD.	COD	R/S	A=
8	Input A.	A	R/S	ST=
9	Input ST.	ST	R/S	SL=
10	Input SL.	SL	R/S	ML=
11	Input ML.	ML	R/S	MC=
12	Input MC.	MC	R/S	MT=
13	Input MT.	MT	R/S	
				Data output
	Rectangular Analysis			
1	Initialize program.		E	OD=
2	Input OD.	OD	R/S	T=
3	Input T.	T	R/S	PD=
4	Input PD.	PD	R/S	LT=
5	Input LT.	LT	R/S	LL=
6	Input LL.	LL	R/S	COD=
7	Input zero.	0	R/S	A=
8	Input A.	A	R/S	ST=
9	Input ST.	ST	R/S	SL=
10	Input SL.	SL	R/S	ML=
11	Input ML.	ML	R/S	MC=
12	Input MC.	MC	R/S	MT=
13	Input MT.	MT	R/S	
				Data output

Registers, Flags, Assignments

Program Number HP-41CV-7 Title Shell Stresses

DATA REGISTERS

00	
01	OD
02	T
03	PD
04	LT
05	LL
06	COD
07	A
08	ST
09	SL
10	ML
11	MC
12	MT
13	Shear area, ST
14	Shear area, SL
15	Shear area, MT
16	Mean diameter/γ
17	LOG β1
18	LOG β2
19	LOG β1
20	LOG β2
21	Area
22	Pipe section modulus
23	0.0
24	-0.45
25	-0.75
26	0.05
27	-0.55
28	-0.60
29	40
30	50
31	40
32	2.2
33	2.0
34	1.8
35	Factor for Ct
36	IND
37	IND
38	IND

DATA REGISTERS

39	IND
40	σA
41	σL
42	σC
43	τT
44	τST
45	τSL
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates
1	C	Print first data set	Print second data set

ASSIGNMENTS

Label	Key	Function	Key
LS	15 (E)		

Rectangular

```
OD= 12.750
T= 0.375
PD= 0.250
LT= 3.500
LL= 2.000
COD= 0.000
R= 100.000
ST= 250.000
SL= 300.000
ML= 100.000
MC= 200.000
MT= 300.000


PER EQ. 2
                    σr=291.
                  σl=2,007.
                  σc=6,394.
                  τt=1,047.
                     τst=57.
                    τsl=120.

FOR NB3652
                    σr=194.
                  σl=1,338.
                  σc=4,263.
                  τt=1,047.
                     τst=57.
                    τsl=120.
```

Circular

```
OD= 8.625
T= 0.322
PD= 0.000
LT= 0.000
LL= 0.000
COD= 2.500
R= 100.000
ST= 250.000
SL= 300.000
ML= 100.000
MC= 200.000
MT= 300.000


PER EQ. 2
                    σr=638.
                  σl=6,303.
                 σc=23,234.
                  τt=1,139.
                    τst=198.
                    τsl=237.

FOR NB3652
                    σr=425.
                  σl=4,202.
                 σc=15,489.
                  τt=1,139.
                    τst=198.
                    τsl=237.
```

OD = 12.75″
T = 0.375″
PAD = 0.25″
LT = 3.5″
LL = 2.0″

R = 100 lb
TS = 250 lb
LS = 300 lb
ML = 100 ft-lb
MC = 200 ft-lb
MT = 300 ft-lb

Ap = (12.75−0.375)(0.375)PI = 14.5790 in^2
Zp = $(12.75)^4 - (12.00)^4$ (PI)/(OD)/32 = 43.8173 in^3
r = (12.75 − 0.375)/2 = 6.1875 in
β_1 = 3.5/(2)/6.1875 = 0.2828
β_2 = 2.0/(2)/6.1875 = 0.1616
X1 = 0 + log(.2828) = −0.5485
Y1 = 0.05 + log(.1616) = −0.7415
η = −((−.5485)(cos40) + (−.7415)(sin40))
minus $1/2.2((-.5485)(\sin 40) - (-.7415)(\cos 40))^2$
= 0.8758
$C_T{}^* = 12(6.1875/.625)^{.64}(.8758)^{1.54}$ = 42.4318
σ_T = 100(42.4318)/(14.5790) = 291.0473

X1 = −0.45 + log(.2828) = −0.9985
Y1 = −0.55 + log(.1616) = −1.3416
η = −((−.9985)(cos50) + (−1.3416)(sin50))
minus $1/2.0((-.9985)(\sin 50) - (-1.3416)(\cos 50))^2$
= 1.6648

$C_L{}^* = 1.2(6.1875/.625)^{.74}(1.6648)^{4.74}$ = 73.3172
SL = 1200(73.3172)/43.8173 = 2007.8968

X1 = −0.75 + log(.2828) = −1.2985
Y1 = −0.60 + log(.1616) = −1.3916
η = −((−1.2985)(cos40) + (−1.3916)(sin40))
minus 1/1.8((−1.2985)(sin40) − (−1.3916)(cos40))
= 1.8595
$C_C{}^* = 1.8(6.1875/.625)^{.90}(1.8595)^{3.40}$ = 116.7534
σc = 2400(116.7534)/43.8173 = 6395.2397
τst = 250/(2)/(3.5)/(.625) = 57.1429
τsl = 300/(2)/(2.0)/(.625) = 120.0000
τt = 3600/((3.5)(2.0)(.625)(1 − (2.0/3.5))/2) = 1047.2727

A_1 = 2(3.5)(2.0) = 14.0000
$Z_{1L} = 4/3(3.5)(2.0)^2$ = 18.6667
$Z_{1C} = 4/3(3.5)^2(2.0)$ = 32.6667
C_T = 291.0473/(100/14.0000) = 40.7466
C_L = 2007.8968/(1200/18.6667) = 31.2340
C_C = 6395.2397/(2400/32.6667) = 87.0464
B_T = 2/3(40.7466) = 27.1644
B_L = 2/3(31.2340) = 20.8227
B_C = 2/3(87.0464) = 58.0309
σ_T' = 27.1644(100)/14.0000 = 194.0314
$\sigma l'$ = 20.8227(1200)/18.6667 = 1338.5998
$\sigma t'$ = 58.0309(2400)/32.6667 = 4263.4903

Sample Problem

Program: HP-41CV-7 Title Shell Stresses

Sample Problem (Sketch if Desired)

OD = 12.75"
T = 0.375"
PAD = 0.25"
LT = 3.5"
LL = 2.0"
R = 100 lb
TS = 250 lb
LS = 300 lb

ML = 100 ft-lb
MC = 200 ft-lb
MT = 300 ft-lb

Input	Function	Display	Comments
	E	OD=	Initializes program. Prompts for OD.
12.75	R/S	T=	Stores OD in R01. Prompts for T.
.375	R/S	PAD=	Stores T in R02. Prompts for PAD.
.25	R/S	LT=	Stores PAD in R03. Prompts for LT.
3.5	R/S	LL=	Stores LT in R04. Prompts for LL.
2	R/S	COD=	Stores LL in R05. Prompts for COD.
0	R/S	R=	Stores a zero in R06. Prompts for R.
100	R/S	ST=	Stores R in R07. Prompts for ST.
250	R/S	SL=	Stores ST in R08. Prompts for SL.
300	R/S	ML=	Stores SL in R09. Prompts for ML.
100	R/S	MC=	Stores ML in R10. Prompts for MC.
200	R/S	MT=	Stores MC in R11. Prompts for MT.
300	R/S	(Printed output) PER EQ. 2 σr=291. σ1=2,007. σc=6,394. τt=1,047 τst=57. τsl=120.	Stores MT in R12. Finds that a rectangular analysis has been called for. Sums the pipe wall thickness with the pad thickness. Calculates the shear areas and stores them in R13, R14, and R15 for ST shear, SL shear, and MT torsion, respectively. Calculates the values of β_1 and β_2 and stores them in R17 through R20. These will be used to calculate X1 and Y1. The thrust load multiplier is stored in R35. The program shifts to the main equation solver.

Input	Function	Display	Comments
		FOR NB 3652 σr=194. σl=1,338. σc=4,263. τt=1,047. τst=57. τsl=120.	The program stores the constants found in WRC-198 for the calculation of X1 and Y1. The mean radius-to-local-thickness is calculated and stored in R16. The input values of the moment are converted to in-lbs. The pipe cross-sectional metal area and the section modulus are calculated and stored in R21 and R22, respectively. X1 and Y1 are calculated, using the previously stored constants and the logs of β_1 and β_2. One at a time, the stresses due to R, ML, and MC are calculated and stored. Then the shear forces are calculated. The first data set is printed with the header "PER EQ. 2." Then the stresses due to R, ML, and MC are adjusted to agree with Equation 21 of WRC-198. The second data set is printed with the header "FOR NB3652."

Coding Form

Program Number HP-41CV-7 Title Shell Stresses

Step/Line	Key Entry	Key Code	Comments
01	♦LBL "LS"		Initialize program.
02	CLA		
03	CLRG		
04	CF 13		
05	"OD="		Store alpha labels for use in input routine. Set R00 as a pointer and counter.
06	ASTO 01		
07	"T="		
08	ASTO 02		
09	"PD="		
10	ASTO 03		
11	"LT="		
12	ASTO 04		
13	"LL="		
14	ASTO 05		
15	"COD="		
16	ASTO 06		
17	"R="		
18	ASTO 07		
19	"ST="		
20	ASTO 08		
21	"SL="		
22	ASTO 09		
23	"ML="		
24	ASTO 10		
25	"MC="		
26	ASTO 11		
27	"MT="		
28	ASTO 12		
29	CLA		
30	1.012		
31	STO 00		
32	FIX 3		
33	CF 12		
34	♦LBL "AA"		Input routine. Uses R00 as a pointer and a counter.
35	SF 12		
36	ARCL IND 00		
37	PROMPT		
38	ACA		
39	CF 12		
40	ACX		
41	STO IND 00		
42	PRBUF		
43	CLA		
44	ISG 00		
45	GTO "AA"		
46	RCL 06		Determine attachment shape.
47	X≠0?		
48	GTO B		
49	RCL 02		Rectangular:

Step/Line	Key Entry	Key Code	Comments
50	ST+ 03		Wall thickness and pad thickness are summed to get a local area thickness. The shear areas are calculated and stored. Shear areas for ST, SL, and MT are stored in R13, R14, and R15, respectively.
51	RCL 04		
52	STO 13		
53	STO 15		
54	RCL 05		
55	STO 14		
56	ST* 15		
57	RCL 03		
58	ST* 13		
59	ST* 14		
60	ST* 15		
61	2		
62	ST* 13		
63	ST* 14		
64	ST/ 15		
65	1		
66	RCL 04		
67	RCL 05		
68	X<Y?		
69	X<>Y		
70	/		
71	+		
72	ST* 15		
73	RCL 01		
74	RCL 02		
75	-		
76	1/X		
77	STO 16		
78	RCL 04		Log β_1 and Log β_2 are calculated and stored. Log β_1 is stored in R17 and R19. Log β_2 is stored in R18 and R20. Shifts to main program.
79	*		
80	LOG		
81	STO 17		
82	STO 19		
83	RCL 16		
84	RCL 05		
85	*		
86	LOG		
87	STO 18		
88	STO 20		
89	12		
90	STO 35		
91	GTO C		
92	♦LBL B		Circular: Wall thickness and pad thickness are summed.
93	RCL 02		
94	ST+ 03		
95	RCL 06		
96	STO 15		
97	STO 14		
98	STO 13		

Step/Line	Key Entry	Key Code	Comments
99	ST* 15		Shear areas are stored, as detailed above.
100	PI		
101	ST* 13		
102	ST* 14		
103	ST* 15		
104	RCL 03		
105	2		
106	/		
107	ST* 13		
108	ST* 14		
109	ST* 15		
110	RCL 06		
111	RCL 01		
112	RCL 02		
113	-		
114	/		
115	STO 16		
116	LOG		Log β (where $\beta_1 = \beta_2 = \beta$) is calculated and stored. Log β for thrust loads is stored in R17 and R18. Log β for moment loading is stored in R19 and R20.
117	STO 17		
118	STO 18		
119	1		
120	RCL 16		
121	-		
122	RCL 16		
123	*		
124	LOG		
125	STO 19		
126	STO 20		
127	18		
128	STO 35		
129	♦LBL C		Main program: Constants are stored for calculation of η, X_1 and Y_1.
130	0		
131	STO 23		
132	-.45		
133	STO 24		
134	-.75		
135	STO 25		
136	.05		
137	STO 26		
138	-.55		
139	STO 27		
140	-.6		
141	STO 28		
142	40		
143	STO 29		
144	STO 31		
145	50		
146	STO 30		
147	2.2		
148	STO 32		

Step/ Line	Key Entry	Key Code	Comments
149	2		
150	STO 33		
151	1.8		
152	STO 34		
153	RCL 01		γ is calculated from mean diameter and local shell thickness. (r/t)
154	RCL 02		
155	-		
156	RCL 03		
157	/		
158	2		
159	/		
160	STO 16		
161	12		Moments are converted from ft-lb to in-lb.
162	ST* 10		
163	ST* 11		
164	ST* 12		
165	RCL 01		Pipe cross-sectional area and section modulus are calculated. Ap is stored in R21. Zp is stored in R22.
166	X↑2		
167	STO 21		
168	X↑2		
169	STO 22		
170	RCL 01		
171	RCL 02		
172	2		
173	*		
174	-		
175	X↑2		
176	ST- 21		
177	X↑2		
178	ST- 22		
179	PI		
180	ST* 21		
181	ST* 22		
182	4		
183	1/X		
184	ST* 21		
185	8		
186	/		
187	ST* 22		
188	RCL 01		
189	ST/ 22		
190	RCL 17		X_1 and Y_1 are calculated for all cases, using constants in memory and calculated values of Log β_1, and Log β_2.
191	ST+ 23		
192	RCL 18		
193	ST+ 26		
194	RCL 19		
195	ST+ 24		
196	ST+ 25		
197	RCL 20		

Step/ Line	Key Entry	Key Code	Comments
198	ST+ 27		
199	ST+ 28		
200	23		Pointers are set.
201	STO 36		
202	29		
203	STO 37		
204	26		
205	STO 38		
206	32		
207	STO 39		
208	FIX 0		
209	XEQ "DA"		Stress due to radial load is calculated and stored in R40.
210	1.54		
211	Y↑X		
212	RCL 16		
213	.64		
214	Y↑X		
215	*		
216	RCL 07		
217	*		
218	RCL 21		
219	/		
220	RCL 35		
221	*		
222	STO 40		
223	XEQ "DA"		Stress due to longitudinal moment is calculated and stored in R41.
224	4.74		
225	Y↑X		
226	RCL 16		
227	.74		
228	Y↑X		
229	*		
230	1.2		
231	*		
232	RCL 10		
233	*		
234	RCL 22		
235	/		
236	STO 41		
237	XEQ "DA"		Stress due to circumferential moment is calculated and stored in R42.
238	3.4		
239	Y↑X		
240	RCL 16		
241	.9		
242	Y↑X		
243	*		
244	1.8		
245	*		
246	RCL 11		

Step/ Line	Key Entry	Key Code	Comments
247	*		
248	RCL 22		
249	/		
250	STO 42		
251	RCL 12		Torsional moment shear stress calculated and stored in R43.
252	RCL 15		
253	/		
254	STO 43		
255	RCL 08		Shear stresses due to shear forces stored in R44 and R45 for τST and τSL, respectively.
256	RCL 13		
257	/		
258	STO 44		
259	RCL 09		
260	RCL 14		
261	/		
262	STO 45		
263	ADV		
264	ADV		
265	SF 01		
266	"PER EQ. 2"		
267	PRA		
268	♦LBL "BB"		Print routine. The first time through, the stresses found from equations 2a, 2b, and 2c are printed. The second time through, the stresses adjusted for Paragraph NB3652 are printed. Each time a header is printed.
269	SF 12		
270	9		
271	ACCHR		
272	CF 12		
273	SF 13		
274	"R="		
275	ARCL 40		
276	ACA		
277	ADV		
278	SF 12		
279	9		
280	ACCHR		
281	CF 12		
282	"L="		
283	ARCL 41		
284	ACA		
285	ADV		
286	SF 12		
287	9		
288	ACCHR		
289	CF 12		
290	"C="		
291	ARCL 42		
292	ACA		
293	ADV		
294	SF 12		
295	14		

Step/Line	Key Entry	Key Code	Comments
296	ACCHR		
297	CF 12		
298	"T="		
299	ARCL 43		
300	ACA		
301	ADV		
302	SF 12		
303	14		
304	ACCHR		
305	CF 12		
306	"ST="		
307	ARCL 44		
308	ACA		
309	ADV		
310	SF 12		
311	14		
312	ACCHR		
313	CF 12		
314	"SL="		
315	ARCL 45		
316	ACA		
317	ADV		
318	ADV		
319	FC?C 01		The stresses σR, σL, and σC are adjusted for NB 3652. The program then jumps to the printing routine.
320	GTO "BC"		
321	2		
322	ENTER↑		
323	3		
324	/		
325	ST* 40		
326	ST* 41		
327	ST* 42		
328	CF 13		
329	"FOR NB3652"		
330	PRA		
331	GTO "BB"		
332	♦LBL "BC"		Program ends.
333	ADV		
334	ADV		
335	CLX		
336	FIX 3		
337	STOP		
338	♦LBL "DA"		Subroutine: η is calculated per WRC-198.
339	RCL IND 36		
340	RCL IND 37		
341	COS		
342	*		
343	RCL IND 38		
344	RCL IND 37		
345	SIN		
346	*		
347	+		
348	CHS		
349	RCL IND 36		
350	RCL IND 37		
351	SIN		
352	*		
353	RCL IND 38		
354	RCL IND 37		
355	COS		
356	*		
357	-		
358	X↑2		
359	RCL IND 39		
360	/		
361	-		
362	STO 00		
363	1		
364	ST+ 36		
365	ST+ 37		
366	ST+ 38		
367	ST+ 39		
368	RCL 00		
369	RTN		
370	.END.		

Chapter **8**

Allowable Pipeway Spans for Steel Pipe

Program TI-59-8

Introduction:

TI-59-8 calculates three different pipeway spans based on three different criteria: maximum allowed deflection of the pipe, maximum allowed bending stress, and maximum allowed stress at the support due to bending and local shell stresses. The program is based on carbon steel pipe and uses fixed beam equations for the bending stress and deflection and an analysis found in Welding Research Council Bulletin #198 for the local stress calculations.

Nomenclature:

Eleven pieces of data may be input to the program:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- PAD: Support reinforcing pad thickness (in); may be zero
- IT: Insulation thickness (in)
- ID: Insulation density (lb/ft^3)
- DEN: Fluid density (lb/ft^3)
- C1: Transverse length of support area (in)
- C2: Longitudinal length of support area (in)
- *S: Allowed bending stress (psi); Std = 8500
- *ΣS: Allowed bending and local stress (psi); Std = 17,000
- *Δ: Maximum allowed deflection (in); Std = 0.375″

For data marked with an asterisk default values are built into the program.

Four user-keys execute the program:

- A: Input data
- B: Execute with default values
- C: Execute with all data input by user
- E: Initialize program

The three allowable span lengths are designated and labeled as follows:

- L1: Maximum span based on allowable deflection (ft)
- L2: Maximum span based on allowable bending stress (ft)
- L3: Maximum span based on the sum of the bending stress and the local stress at the support point (ft)

Method:

The calculations of the first two allowable spans are based on a continuously loaded beam that is fixed at both ends. For a deflection-based span, the formula is:

$$L1 = \sqrt[4]{\frac{(384)(E)(I)(\text{Allowable deflection})}{(w)}} \times 0.9$$

For a span based on allowable bending stress, the equation is:

$$L2 = \sqrt{\frac{(12)(Z)(\text{Allowable bending stress})}{(w)}}$$

For spans based on the combined stress allowable at the support point, the equation is:

$$L3 = \frac{\dfrac{-(Ct)(w)}{(Ap)} + \sqrt{\dfrac{(Ct)^2(w)^2}{(Ap)^2} + \dfrac{(\text{Combined stress allowable})(w)}{(3)(Z)}}}{\dfrac{(w)}{(6)(Z)}}$$

where

E = Pipe modulus of elasticity = 27.9EE6 psi
I = Pipe moment of inertia
w = Pipe weight per inch
Z = Pipe section modulus
Ap = Pipe metal area
Ct = Pipe support area shape coefficient

The shape coefficient is derived from a study in Welding Research Council Bulletin #198 and is derived as follows:

$$Ct = 12(R/T)^{.64}(N)^{1.54}$$

$$N = -(X1 \text{ COS } 40 + Y1 \text{ SIN } 40) - \frac{1}{2.2}(X1 \text{ SIN } 40 - Y1 \text{ COS } 40)^2$$

$$X1 = \log(C1/OD)$$

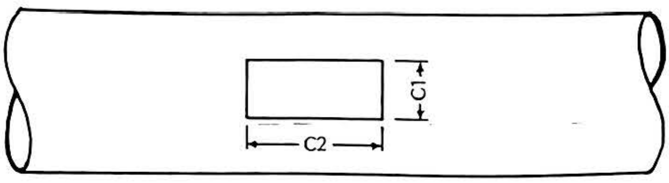
$$Y1 = 0.05 + \log(C2/OD)$$

R = pipe radius
t = thickness of pipe plus thickness of pad (if any)

Limitations:

TI-59-8 deals only with steel pipe. Each set of input data is used only once; that is, no data carry over to the next analysis. After the initial run, the program is self-initializing. The analysis will not allow the value of C2 to exceed the outside diameter of the pipe. Only English units may be used.

Figure 8.1 Sketch Defining C1 and C2



PLAN VIEW

User Instructions

Program Number TI-59-8 **Title** Allowable Pipeway Spans

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic card, both sides.			
2	Initialize program.		E	0
3	Input OD.	OD	A	OD
4	Input T.	T	A	T
5	Input PAD.	PAD	A	PAD
6	Input IT.	IT	A	IT
7	Input ID.	ID	A	ID
8	Input DEN.	DEN	A	DEN
9	Input C1.	C1	A	C1
10	Input C2.	C2	A	C2
11	Execute program with internal allowables.		B	0
	- -			
12	Input allowed bending stress.	S	A	S
13	Input allowed combined stress.	ΣS	A	ΣS
14	Input allowed deflection.	Δ	A	Δ
15	Execute.		C	0

If the user decides to use the internal allowables, Steps 12 to 15 cannot be executed. If the user inputs his own allowables, Step 11 is *skipped.* The two procedures are *mutually exclusive.*

Data Register Contents

REGISTER	DATA	REGISTER	DATA
00	IND	30	
01	OD	31	
02	T	32	
03	PAD	33	
04	IT	34	
05	ID	35	
06	DEN	36	
07	C1	37	
08	C2	38	
09	S	39	
10	ΣS	40	
11	Δ	41	
12	27,900,000 (E for carbon steel)	42	
13	Pipe metal area	43	
14	Moment of inertia	44	
15	Weight per inch (WPI) insulation	45	
16	WPI fluid	46	
17	WPI pipe	47	
18	Total WPI	48	
19	L1	49	
20	L2	50	
21	L3	51	
22	IND	52	
23		53	
24	X1	54	
25	X2	55	
26		56	
27	Ct	57	
28		58	
29		59	

24.	OD	Pipe outside diameter (in)
0.375	T	Pipe thickness (in)
0.375	PAD	Support reinforcing pad thickness (in)
3.	IT	Insulation thickness (in)
11.	ID	Insulation density (lb/ft^3)
62.4	DEN	Fluid density (lb/ft^3)
2.88	C1	Transverse length of support area (in)
4.5	C2	Longitudinal length of support area (in)
8500.	S	Allowed bending stress (psi)
17000.	ΣS	Allowed bending + local stress (psi)
0.375	[illegible]	Allowed deflection (in)
56.14	L1	Maximum span based on deflection (ft)
67.92	L2	Maximum span based on bending stress (ft)
17.74	L3	Maximum span based on combined stress (ft)

EXAMPLE CALCULATIONS

OD = 24″
T = 0.375″
PAD = 0.375″
IT = 3″
ID = 11 lbs/ft^3
DEN = 62.4 lbs/cu.ft

C1 = 2.88″
C2 = 4.5″
S = 8500 psi
ΣS = 17000 psi
Δ = 0.375″

Pipe metal area = (24 − 0.375)(0.375)(PI) = 27.833 in^2
Pipe moment of inertia = ((24)^4 − (23.25)^4)(PI)/64 = 1942.299 in^4
Pipe weight-per-inch:

Pipe: (27.833)(0.284) = 7.904 #/in
Insulation: (24 + 3)(3)(PI)(11)/1728 = 1.620 #/in
Fluid: (23.25)^2(PI)/4 × (62.4)/1728 = 15.331 #/in

Total = 7.904 + 1.620 + 15.331 = 24.855 #/in

$$L1 = \sqrt[4]{\frac{(384)(27.9EE6)(1942.299)(0.375)}{(24.855)}} \times 0.9 = 673.689'' = 56.141 \text{ ft}$$

$$\text{check:} \quad \Delta = \frac{(w)(L)^4}{(384)(E)(I)} = \frac{(24.855)(673.689/0.9)^4}{(384)(27.9EE6)(1942.299)} = 0.375''$$

$$L2 = \sqrt{\frac{(12)(1942.299)(2)(8500)/24}{(24.855)}} = 815.006'' = 67.917 \text{ ft}$$

$$\text{check:} \quad \sigma = \frac{(w)(L)^2}{(12)(Z)} = \frac{(24.855)(815.006)^2}{(12)(161.858)} = 8500 \text{ psi}$$

L3: η(WRC-198) = −(X1 COS 40 + Y1 SIN 40) −1/2.2(X1 SIN 40 − Y1 COS 40)^2

X1 = log(1.44/12) = −0.921
Y1 = 0.05 + log(2.25/12) = −0.677
η = −((−.921)(COS 40) + (−.677)(SIN 40)) −1/2.2((−.921)(SIN 40) − (−.677)(cos 40))^2
= 1.138
Ct = 12(12/.75)$^{.64}$(1.138)$^{1.54}$ = 86.366

$$L3 = \frac{-\dfrac{(86.366)(24.855)}{(27.833)} + \sqrt{\dfrac{(86.366)^2(24.855)^2}{(27.833)^2} + \dfrac{(17{,}000)(24{,}855)}{(3)(161.858)}}}{\dfrac{(24.855)}{(6)(161.858)}}$$

= 212.900″
= 17.742 ft

check:

$\tau loc. = (Ct)(P)/Ap$
$= (86.366)(212.900 \times 24.855)/27.833 = 16{,}420$ psi

$$\tau b = \frac{(24.855)(212.900)^2}{(12)(161.858)} = 580 \text{ psi}$$

$$\begin{array}{r} 16{,}420 \\ +\quad 580 \\ \hline 17{,}000 \end{array}$$

Sample Problem

Program: TI-59-8

OD = 24"
T = 0.375"
PAD = 0.375"
IT = 3"
ID = 4 lb/ft^3
DEN = 62.4 lb/ft^3
C1 = 2.88"
C2 = 4.5"
S = 8500 psi
ΣS = 17,00 psi
Δ = 0.375"

Step	Input	Key Stroke	Display	Printer		Comments
INITIALIZE PROGRAM BY PRESSING "E"						
1	24	A	24.	24.	OD	Stores OD in R01.
2	.375	A	0.375	0.375	T	Stores T in R02.
3	.375	A	0.375	0.375	PAD	Stores D in R03.
4	3	A	3.	3.	IT	Stores IT in R04.
5	11	A	11.	11.	ID	Stores ID in R05.
6	62.4	A	62.4	62.4	DEN	Stores DEN in R06.
7	2.88	A	2.88	2.88	C1	Stores C1 in R07.
8	4.5	A	4.5	4.5	C2	Stores C2 in R08.
9		B	0.	8500.	S	
				17000.	ΣS	
				0.375	Δ	The program labels, prints, and stores the internal values for bending stress allowable, combined stress allowable, and maximum allowed deflection. The program then calculates the allowed span for deflection and stores the value in R19. Then the span for bending stress is calculated and stored in R20. Finally, the program calculates the shape factor for the local area according to WRC-198. Using the shape factor the program calculates the stress intensity factor according to WRC-198. The span based on the combination of bending stress and the local stress is calculated and stored in R21. The results are then printed out.
				56.14	L1	
				67.92	L2	
				17.74	L3	

Coding Form

Program Number TI-59-8 **Title** Allowable Pipeway Spans

Loc	Code	Key	Comments
000	76	LBL	Initializing routine.
001	15	E	Sets alpha labels.
002	03	3	
003	02	2	
004	01	1	
005	06	6	
006	42	STO	
007	01	01	
008	03	3	
009	07	7	
010	42	STO	
011	02	02	
012	03	3	
013	03	3	
014	01	1	
015	03	3	
016	01	1	
017	06	6	
018	42	STO	
019	03	03	
020	02	2	
021	04	4	
022	03	3	
023	07	7	
024	42	STO	
025	04	04	
026	02	2	
027	04	4	
028	01	1	
029	06	6	
030	42	STO	
031	05	05	
032	01	1	
033	06	6	
034	01	1	
035	07	7	
036	03	3	
037	01	1	
038	42	STO	
039	06	06	
040	01	1	
041	05	5	
042	00	0	
043	02	2	
044	42	STO	
045	07	07	
046	01	1	
047	05	5	
048	00	0	
049	03	3	
050	42	STO	
051	08	08	
052	03	3	
053	06	6	
054	42	STO	
055	09	09	
056	07	7	
057	07	7	
058	03	3	
059	06	6	

Loc	Code	Key	Comments
060	42	STO	
061	10	10	
062	07	7	
063	05	5	
064	42	STO	
065	11	11	
066	00	0	Set pointer to zero.
067	42	STO	
068	00	00	
069	91	R/S	
070	76	LBL	Input routine:
071	11	A	Uses R00 as a
072	69	OP	pointer.
073	20	20	
074	63	EX*	
075	00	00	
076	69	OP	
077	04	04	
078	73	RC*	
079	00	00	
080	69	OP	
081	06	06	
082	91	R/S	
083	76	LBL	Main control for
084	12	B	program-supplied
085	69	OP	allowables.
086	20	20	
087	73	RC*	
088	00	00	
089	69	OP	
090	04	04	
091	08	8	
092	05	5	Prints standard
093	00	0	allowables and
094	00	0	stores them in
095	69	OP	memory.
096	06	06	
097	72	ST*	
098	00	00	
099	69	OP	
100	20	20	
101	73	RC*	
102	00	00	
103	69	OP	
104	04	04	
105	01	1	
106	07	7	
107	00	0	
108	00	0	
109	00	0	
110	69	OP	
111	06	06	
112	72	ST*	
113	00	00	
114	69	OP	
115	20	20	
116	73	RC*	
117	00	00	
118	69	OP	
119	04	04	

Loc	Code	Key	Comments
120	93	.	
121	03	3	
122	07	7	
123	05	5	
124	69	OP	
125	06	06	
126	72	ST*	
127	00	00	
128	76	LBL	Stores modulus of
129	13	C	elasticity for
130	02	2	carbon steel in
131	07	7	R12.
132	93	.	
133	09	9	
134	52	EE	
135	06	6	
136	42	STO	
137	12	12	
138	25	CLR	
139	43	RCL	Calculates pipe
140	01	01	metal area, and
141	33	X^2	weight-per-inch
142	42	STO	values for pipe,
143	13	13	fluid, and
144	42	STO	insulation. Also
145	17	17	calculates pipe
146	94	+/-	moment of inertia.
147	42	STO	
148	15	15	
149	33	X^2	
150	42	STO	
151	14	14	
152	43	RCL	
153	01	01	
154	75	-	
155	02	2	
156	65	×	
157	43	RCL	
158	02	02	
159	95	=	
160	33	X^2	Pipe WPI is
161	42	STO	stored in R17.
162	16	16	Insulation WPI is in
163	94	+/-	R15. Fluid WPI
164	44	SUM	is in R16. Metal
165	13	13	area is stored in
166	44	SUM	R13, and moment
167	17	17	of inertia is in R14.
168	33	X^2	
169	94	+/-	
170	44	SUM	
171	14	14	
172	43	RCL	
173	01	01	
174	85	+	
175	02	2	
176	65	×	
177	43	RCL	
178	04	04	
179	95	=	

Loc	Code	Key	Comments
180	33	X²	
181	44	SUM	
182	15	15	
183	89	π	
184	55	÷	
185	04	4	
186	95	=	
187	49	PRD	
188	13	13	
189	49	PRD	
190	15	15	
191	49	PRD	
192	16	16	
193	49	PRD	
194	17	17	
195	55	÷	
196	01	1	
197	06	6	
198	95	=	
199	49	PRD	
200	14	14	
201	01	1	Change units to #/in³ for density of fluid and insulation.
202	07	7	
203	02	2	
204	08	8	
205	35	1/X	
206	49	PRD	
207	05	05	
208	49	PRD	
209	06	06	
210	43	RCL	Sets C2 to the lesser of the input value and the pipe OD.
211	01	01	
212	32	X⇄T	
213	43	RCL	
214	08	08	
215	22	INV	
216	77	GE	
217	24	CE	
218	32	X⇄T	
219	76	LBL	
220	24	CE	
221	42	STO	
222	08	08	
223	93	.	Complete WPI calculations.
224	02	2	
225	08	8	
226	04	4	
227	49	PRD	
228	17	17	
229	43	RCL	
230	05	05	
231	49	PRD	
232	15	15	
233	43	RCL	
234	06	06	
235	49	PRD	
236	16	16	
237	43	RCL	Total WPI is stored in R18.
238	15	15	
239	85	+	

Loc	Code	Key	Comments
240	43	RCL	
241	16	16	
242	85	+	
243	43	RCL	
244	17	17	
245	95	=	
246	42	STO	
247	18	18	
248	03	3	Calculate L based on allowed deflection; store L1 in R19.
249	08	8	
250	04	4	
251	65	×	
252	43	RCL	
253	11	11	
254	65	×	
255	43	RCL	
256	12	12	
257	65	×	
258	43	RCL	
259	14	14	
260	55	÷	
261	43	RCL	
262	18	18	
263	95	=	
264	34	√X	
265	34	√X	
266	65	×	
267	93	.	
268	09	9	
269	95	=	
270	42	STO	
271	19	19	
272	43	RCL	Calculate L based on allowed bending stress; store L2 in R20.
273	14	14	
274	55	÷	
275	43	RCL	
276	01	01	
277	65	×	
278	02	2	
279	95	=	
280	42	STO	
281	22	22	
282	65	×	
283	01	1	
284	02	2	
285	65	×	
286	43	RCL	
287	09	09	
288	55	÷	
289	43	RCL	
290	18	18	
291	95	=	
292	34	√X	
293	42	STO	
294	20	20	
295	43	RCL	Begin L3 calculation. Log β_1 is stored in R24.
296	07	07	
297	55	÷	
298	43	RCL	
299	01	01	

Loc	Code	Key	Comments
300	95	=	
301	29	LOG	
302	42	STO	
303	24	24	
304	43	RCL	Log β_2 + .05 is stored in R25. These are X_1 and Y_1 according to WRC-198.
305	08	08	
306	55	÷	
307	43	RCL	
308	01	01	
309	95	=	
310	28	LOG	
311	85	+	
312	93	.	
313	00	0	
314	05	5	
315	95	=	
316	42	STO	
317	25	25	
318	53	(	Calculate η per WRC-198.
319	43	RCL	
320	24	24	
321	65	×	
322	04	4	
323	00	0	
324	39	COS	
325	85	+	
326	43	RCL	
327	25	25	
328	65	×	
329	04	4	
330	00	0	
331	38	SIN	
332	54	)	
333	94	+/-	
334	75	−	
335	01	1	
336	55	÷	
337	02	2	
338	93	.	
339	02	2	
340	65	×	
341	53	(	
342	43	RCL	
343	24	24	
344	65	×	
345	04	4	
346	00	0	
347	38	SIN	
348	75	−	
349	43	RCL	
350	25	25	
351	65	×	
352	04	4	
353	00	0	
354	39	COS	
355	54	)	
356	33	X²	
357	95	=	
358	45	YX	Calculate CT per WRC-198.
359	01	1	

Loc	Code	Key	Comments
360	93	.	
361	05	5	
362	04	4	
363	65	×	
364	53	(	
365	43	RCL	
366	01	01	
367	55	÷	
368	53	(	
369	43	RCL	
370	02	02	
371	85	+	
372	43	RCL	
373	03	03	
374	54	)	
375	55	÷	
376	02	2	
377	54	)	
378	45	Y^X	
379	93	.	
380	06	6	
381	04	4	
382	65	×	
383	01	1	
384	02	2	Store CT in R27.
385	95	=	
386	42	STO	
387	27	27	
388	94	+/-	Calculate span based on the sum of bending stress and local shell stress at the support.
389	65	×	
390	43	RCL	
391	18	18	
392	55	÷	
393	43	RCL	
394	13	13	
395	85	+	
396	53	(	
397	43	RCL	
398	27	27	
399	33	X^2	
400	65	×	
401	43	RCL	
402	18	18	
403	33	X^2	
404	55	÷	
405	43	RCL	
406	13	13	
407	33	X^2	
408	85	+	
409	43	RCL	
410	10	10	
411	65	×	
412	43	RCL	
413	18	18	
414	55	÷	
415	03	3	
416	55	÷	
417	43	RCL	
418	22	22	
419	54	)	
420	34	√X	
421	54	)	
422	65	×	
423	06	6	
424	65	×	
425	43	RCL	
426	22	22	
427	55	÷	
428	43	RCL	
429	18	18	
430	95	=	L3 is stored in R21.
431	42	STO	
432	21	21	
433	58	FIX	Print L1, L2, and L3, in feet.
434	02	02	
435	01	1	
436	02	2	
437	35	1/X	
438	49	PRD	
439	19	19	
440	49	PRD	
441	20	20	
442	49	PRD	
443	21	21	
444	98	ADV	
445	02	2	
446	07	7	
447	00	0	
448	02	2	
449	69	OP	
450	04	04	
451	43	RCL	
452	19	19	
453	69	OP	
454	06	06	
455	02	2	
456	07	7	
457	00	0	
458	03	3	
459	69	OP	
460	04	04	
461	43	RCL	
462	20	20	
463	69	OP	
464	06	06	
465	02	2	
466	07	7	
467	00	0	
468	04	4	
469	69	OP	
470	04	04	
471	43	RCL	
472	21	21	
473	69	OP	
474	06	06	
475	22	INV	
476	58	FIX	
477	98	ADV	
478	98	ADV	
479	81	RST	Initialize.

Pipeway Spans

Pipe outside diameter (in)
Pipe thickness (in)
Support reinforcing pad thickness (in)
Insulation thickness (in)
Insulation density (lb/ft^3)
Fluid density (lb/ft^3)
Transverse length of support area (in)
Longitudinal length of support area (in)
Allowed bending stress (psi)
Allowed bending + local stress (psi)
Allowed deflection (in)

Maximum span based on deflection (ft)
Maximum span based on bending stress (ft)
Maximum span based on combined stress (ft)

Program HP-41CV-8: Pipeway Spans for Steel Pipe

Introduction:

HP-41CV-8 calculates three different pipeway spans based on three different criteria: maximum allowed deflection of the pipe, maximum allowed bending stress, and maximum allowed stress at the support due to bending and local shell stresses. The program is based on carbon steel pipe and uses fixed beam equations for the bending stress and deflection and an analysis found in Welding Research Council Bulletin #198 for the local stress calculations.

Nomenclature:

Eleven pieces of data may be input to the program:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- PAD: Support reinforcing pad thickness (in); may be zero
- IT: Insulation thickness (in)
- ID: Insulation density (lb/ft^3)
- DEN: Fluid density (lb/ft^3)
- C1: Transverse length of support area (in)
- C2: Longitudinal length of support area (in)
- *BS: Allowed bending stress (psi); Std = 8500
- *TS: Allowed bending and local stress (psi); Std = 17,000
- *DLTA: Maximum allowed deflection (in); Std = 0.375″

For data marked with an asterisk, default values are built into the program.

Three keys are used to execute the program:

- E: Initialize the program
- R/S: Used for data input
- A: Execute using default values

The three allowable span lengths are designated and labeled as follows:

- $L\Delta$: Maximum span based on allowable deflection (ft)
- L_{bs}: Maximum span based on allowable bending stress (ft)
- L_{ts}: Maximum span based on the sum of the bending stress and the local stress at the support point (ft)

Method:

The calculations of the first two allowable spans are based on a continuously loaded beam that is fixed at both ends. For a deflection-based span, the formula is:

$$L\Delta = \sqrt[4]{\frac{(384)(E)(I)(\text{Allowable deflection})}{(w)}} \times 0.9$$

For a span based on allowable bending stress, the equation is:

$$L_{bs} = \sqrt{\frac{(12)(Z)(\text{Allowable bending stress})}{(w)}}$$

For spans based on the combined stress allowable at the support point, the equation is:

$$L_{ts} = \frac{\dfrac{-(Ct)(w)}{(Ap)} + \sqrt{\dfrac{(Ct)^2(w)^2}{(Ap)^2} + \dfrac{(\text{Combined stress allowable})(w)}{(3)(Z)}}}{\dfrac{(w)}{(6)(Z)}}$$

where

E = Pipe modulus of elasticity = 27.9EE6 psi
I = Pipe moment of inertia
w = Pipe weight per inch
Z = Pipe section modulus
Ap = Pipe metal area
Ct = Pipe support area shape coefficient

The shape coefficient is derived from a study in Welding Research Council Bulletin #198 and is derived as follows:

$$Ct = 12(R/T)^{.64}(N)^{1.54}$$

$$N = -(X1\ \text{COS}\ 40 + Y1\ \text{SIN}\ 40) - \frac{1}{2.2}(XI\ \text{SIN}\ 40 - Y1\ \text{COS}\ 40)^2$$

$$X1 = \log(C1/OD)$$

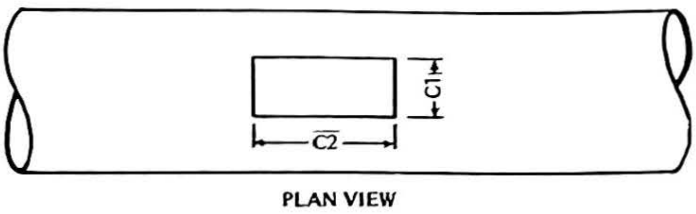
$$Y1 = 0.05 + \log(C2/OD)$$

R = pipe radius
t = thickness of pipe plus thickness of pad (if any)

Limitations:

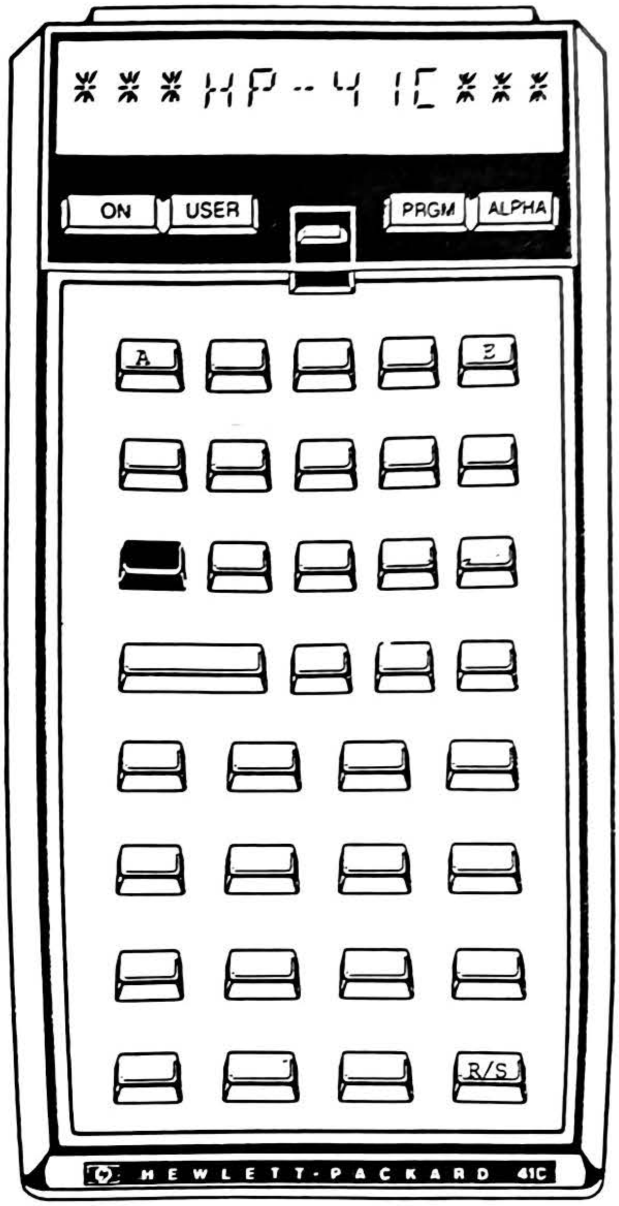
HP-41CV-8 deals only with steel pipe. Each set of input data is used only once; that is, no data carry over to the next analysis. After the initial run, the program is self-initializing. The analysis will not allow the value of C2 to exceed the OD of the pipe. Only English units may be used.

Figure 8.2 Sketch Defining C1 and C2

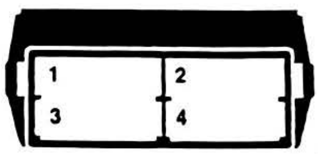


Keyboard Card Labeling

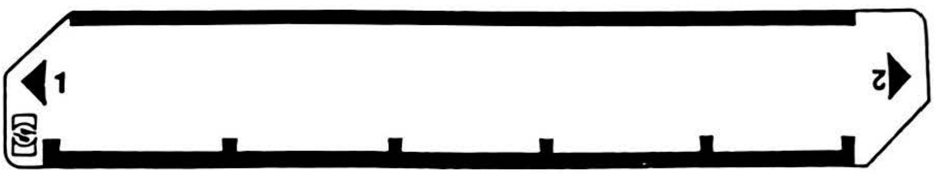
KEYBOARD



SYSTEM CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-8 **Title** Allowable Pipeway Spans

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards.			
2	Initialize program.		E	OD=
3	Input OD.	OD	R/S	T=
4	Input T.	T	R/S	PAD=
5	Input PAD.	PAD	R/S	IT=
6	Input IT.	IT	R/S	ID=
7	Input ID.	ID	R/S	DEN=
8	Input DEN.	DEN	R/S	C1=
9	Input C1.	C1	R/S	C2=
10	Input C2.	C2	R/S	BS=
11	If the default values are used:			
	Execute.		A	OD=
	If nonstandard values are used:			
12	Input BS.	BS	R/S	TS=
13	Input TS.	TS	R/S	DLTA=
14	Input DLTA.	DLTA	R/S	OD=

Registers, Flags, Assignments

Program Number HP-41CV-8 **Title** Allowable Pipeway Spans

DATA REGISTERS

00	IND
01	OD
02	T
03	PAD
04	IT
05	ID
06	DEN
07	C1
08	C2
09	BS
10	TS
11	DLTA
12	27,900,000
13	Metal area
14	Moment of inertia
15	WPI pipe
16	WPI insulation
17	WPI metal
18	Total WPI
19	L (dlta)
20	L (bs)
21	L (ts)
22	Pipe section modulus
23	
24	LOG B1
25	LOG B2
26	
27	Ct
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	
38	

DATA REGISTERS

39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates

ASSIGNMENTS

Label	Key	Function	Key
AA	11 (A)		
PS	15 (E)		

Example Output

```
OD= 24.000
T= 0.375
PAD= 0.375
IT= 3.000
ID= 11.000
DEN= 62.400
C1= 2.880
C2= 4.500
BS= 8,500.000
TS= 17,000.000
DLTA= 0.375

        Lb= 56.14
       Lbs= 67.92
       Lts= 17.74
```

OD = 24"
T = 0.375"
TAD = 0.375"
IT = 3"
ID = 11 lbs/ft^3
DEN = 62.4 lbs/cu.ft

C1 = 2.88"
C2 = 4.5"
BS = 8500 psi
TS = 17000 psi
Δ = 0.375"

Pipe metal area = (24 − 0.375)(0.375)(PI) = 27.833 in^2
Pipe moment of inertia = ((24)^4 − (23.25)^4)(PI)/64 = 1942.299 in^4
Pipe weight-per-inch:

Pipe: (27.833)(0.284) = 7.904 #/in
Insulation: (24 + 3)(3)(PI)(11)/1728 = 1.620 #/in
Fluid: (23.25)^2(PI)/4 × (62.4)/1728 = 15.331 #/in

Total = 7.904 + 1.620 + 15.331 = 24.855 #/in

$$L1 = \sqrt[4]{\frac{(384)(27.9EE6)(1942.299)(0.375)}{(24.855)}} \times 0.9 = 673.689'' = 56.141 \text{ ft}$$

$$\text{check} \quad \Delta = \frac{(w)(L)^4}{(384)(E)(I)} = \frac{(24.855)(673.689/0.9)^4}{(384)(27.9EE6)(1942.299)} = 0.375''$$

$$L2 = \sqrt{\frac{(12)(1942.299)(2)(8500)/24}{(24.855)}} = 815.006'' = 67.917 \text{ ft}$$

$$\text{check} \quad \sigma = \frac{(w)(L)^2}{(12)(Z)} = \frac{(24.855)(815.006)^2}{(12)(161.858)} = 8500 \text{ psi}$$

L3: η(WRC-198) = −(X1 COS 40 + Y1 SIN 40) −1/2.2(X1 SIN 40 − Y1 COS 40)^2

X1 = log(1.44/12) = −0.921
Y1 = 0.05 + log(2.25/12) = −0.677
η = −((−.921)(COS 40) + (−.677)(SIN 40)) −1/2.2((−.921)(SIN 40) − (−.677)(cos 40))^2
= 1.138
Ct = 12(12/.75)$^{.64}$(1.138)$^{1.54}$ = 86.366

$$L3 = \frac{-\frac{(86.366)(24.855)}{(27.833)} + \sqrt{\frac{(86.366)^2(24.855)^2}{(27.833)^2} + \frac{(17{,}000)(24.855)}{(3)(161.858)}}}{\frac{(24.855)}{(6)(161.858)}}$$

= 212.900"
= 17.742 ft

check:

τloc. = (Ct)(P)/Ap
= (86.366)(212.900 × 24.855)/27.833 = 16,420 psi

$$\tau b = \frac{(24.855)(212.900)^2}{(12)(161.858)} = 580 \text{ psi}$$

$$\begin{array}{r} 16{,}420 \\ \underline{+ \quad 580} \\ 17{,}000 \end{array}$$

Sample Problem

Program: HP-41CV-8 Title Allowable Pipeway Spans

Sample Problem (Sketch if Desired)

OD = 24"
T = 0.375"
PAD = 0.375"
IT = 3"
ID = 11 lb/ft^3
DEN = 62.4 lb/ft^3
C1 = 2.88"
C2 = 4.5"
BS = 8500 psi
TS = 17,000 psi
DLTA = 0.375"

Input	Function	Display	Comments
	E	OD=	Initializes program. Prompts for the input of OD.
24	R/S	T=	Stores OD in R01. Prompts for T.
.375	R/S	PAD=	Stores T in R02. Prompts for PAD.
.375	R/S	IT=	Stores PAD in R03. Prompts for IT.
3	R/S	ID=	Stores IT in R04. Prompts for ID.
11	R/S	DEN=	Stores ID in R05. Prompts for DEN.
62.4	R/S	C1=	Stores DEN in R06. Prompts for C1.
2.88	R/S	C2=	Stores C1 in R07. Prompts for C2.
4.5	R/S	BS=	Stores C2 in R08. Prompts for BS.
	A		Stores and prints the default values for BS, TS, and DLTA. BS is stored in R09, TS is stored in R10, and DLTA is stored in R11.
			The program first stores the modulus of elasticity for carbon steel (27.9EE6 psi) for later use. Then the weight-per-inch of the pipe is calculated, along with the moment of inertia and metal area of the pipe. The input values of ID and DEN are converted to lbs/in^3. Next the program chooses the lesser of the input value of C2 and the pipe OD for use in the local stress calculations. The program then calculates the span based on deflection and stores it in R19. The span based on bending stress is calculated and stored in R20.

Input	Function	Display	Comments
			Then the shell stress analysis per WRC-198 begins by calculating the shape factor. Using the total stress value, the program calculates the span based on bending stress and the local shell stress and stores it in R21. The spans are all converted to feet and printed. After printing, the program reinitializes itself for the next analysis.
		OD=	

Coding Form

Program Number HP-41CV-8 Title Allowable Pipeway Spans

Step/Line Key Entry	Key Code	Comments
01♦LBL "PS"		Initializing routine: Sets all alpha labels and the pointer R00.
02 "OD"		
03 ASTO 01		
04 "T"		
05 ASTO 02		
06 "PAD"		
07 ASTO 03		
08 "IT"		
09 ASTO 04		
10 "ID"		
11 ASTO 05		
12 "DEN"		
13 ASTO 06		
14 "C1"		
15 ASTO 07		
16 "C2"		
17 ASTO 08		
18 "BS"		
19 ASTO 09		
20 "TS"		
21 ASTO 10		
22 "DLTA"		
23 ASTO 11		
24 1.011		
25 STO 00		
26♦LBL 10		Input routine: Uses R00 as pointer and counter.
27 CLA		
28 ARCL IND 00		
29 "⊢="		
30 SF 12		
31 PROMPT		
32 ACA		
33 CF 12		
34 FIX 3		
35 ACX		
36 STO IND 00		
37 PRBUF		
38 CLA		
39 ISG 00		
40 GTO 10		
41 GTO "AB"		
42♦LBL "AA"		Main control for default values of bending stress allowables, total stress allowables, and deflection. Stores and prints default values.
43 CLA		
44 .375		
45 ENTER↑		
46 17000		
47 ENTER↑		
48 8500		
49 ENTER↑		

Step/Line Key Entry	Key Code	Comments
50♦LBL 11		
51 ARCL IND 00		
52 "⊢="		
53 SF 12		
54 ACA		
55 RDN		
56 CF 12		
57 ACX		
58 STO IND 00		
59 PRBUF		
60 CLA		
61 ISG 00		
62 GTO 11		
63♦LBL "AB"		Main control for user-supplied allowables. Store E.
64 27.9 E6		
65 STO 12		
66 RCL 01		Calculates weight-per-inch values for pipe, insulation, and fluid. Also calculates metal area and moment of inertia. Pipe WPI is in R17. Insulation WPI is in R15. Fluid WPI is in R16. Metal area is in R13. Moment of inertia is in R14.
67 X↑2		
68 STO 13		
69 STO 17		
70 CHS		
71 STO 15		
72 RCL 01		
73 RCL 02		
74 2		
75 *		
76 -		
77 X↑2		
78 STO 16		
79 ST- 13		
80 ST- 17		
81 RCL 01		
82 RCL 04		
83 2		
84 *		
85 +		
86 X↑2		
87 ST+ 15		
88 PI		
89 4		
90 /		
91 ST* 13		
92 ST* 15		
93 ST* 16		
94 ST* 17		
95 RCL 01		
96 X↑2		
97 X↑2		
98 RCL 01		

Step/Line Key Entry	Key Code	Comments
99 RCL 02		
100 2		
101 *		
102 -		
103 X↑2		
104 X↑2		
105 -		
106 PI		
107 *		
108 64		
109 /		
110 STO 14		
111 1728		Change units of ID and DEN to lbs/in^3.
112 ST/ 05		
113 ST/ 06		
114 RCL 01		Chooses smaller of input C2 and pipe OD for use in WRC-198 analysis.
115 RCL 08		
116 X<=Y?		
117 GTO 13		
118 X<>Y		
119♦LBL 13		
120 STO 08		
121 .284		Complete WPI calculations.
122 ST* 17		
123 RCL 05		
124 ST* 15		
125 RCL 06		
126 ST* 16		
127 RCL 15		Total WPI is stored in R19.
128 RCL 16		
129 RCL 17		
130 +		
131 +		
132 STO 18		
133 384		Span calculation for deflection criteria is performed.
134 RCL 11		
135 *		
136 RCL 12		
137 *		
138 RCL 14		LΔ is in R19.
139 *		
140 RCL 18		
141 /		
142 SQRT		
143 SQRT		
144 .9		
145 *		
146 STO 19		
147 RCL 14		

Step/Line	Key Entry	Key Code	Comments
148	RCL 01		Bending stress span calculation is performed. L_{bs} is in R20.
149	/		
150	2		
151	*		
152	STO 22		
153	12		
154	*		
155	RCL 09		
156	*		
157	RCL 18		
158	/		
159	SQRT		
160	STO 20		
161	RCL 07		Begin span calculations for bending stress plus local shell stress criteria. Calculate X_1 and Y_1 per WRC-198.
162	RCL 01		
163	/		
164	LOG		
165	STO 24		
166	RCL 08		
167	RCL 01		
168	/		
169	LOG		
170	.05		
171	+		
172	STO 25		
173	RCL 24		Calculate η per WRC-198.
174	40		
175	COS		
176	*		
177	RCL 25		
178	40		
179	SIN		
180	*		
181	+		
182	CHS		
183	RCL 24		
184	40		
185	SIN		
186	*		
187	RCL 25		
188	40		
189	COS		
190	*		
191	-		
192	X↑2		
193	2.2		
194	/		
195	-		
196	1.54		
197	Y↑X		Calculate Ct per WRC-198. Store in R27.
198	RCL 01		
199	RCL 02		
200	RCL 03		
201	+		
202	/		
203	2		
204	/		
205	.64		
206	Y↑X		
207	*		
208	12		
209	*		
210	STO 27		
211	CHS		
212	RCL 18		Span calculation for total stress is performed.
213	*		
214	RCL 13		
215	/		
216	RCL 27		
217	X↑2		
218	RCL 18		
219	X↑2		
220	*		
221	RCL 13		L_{ts} is stored in R22.
222	X↑2		
223	/		
224	RCL 10		
225	RCL 18		
226	*		
227	3		
228	/		
229	RCL 22		
230	/		
231	+		
232	SQRT		
233	+		
234	RCL 18		
235	6		
236	RCL 22		
237	*		
238	/		
239	/		
240	STO 21		
241	12		Convert spans to feet.
242	ST/ 19		
243	ST/ 20		
244	ST/ 21		
245	ADV		Print L_{Δ}.
246	FIX 2		
247	SF 12		
248	"L"		
249	ACA		
250	CF 12		
251	SF 13		
252	8		
253	ACCHR		
254	CF 13		
255	SF 12		
256	"="		
257	ACA		
258	CF 12		
259	RCL 19		
260	ACX		
261	ADV		
262	SF 12		Print L_{bs}.
263	"L"		
264	ACA		
265	CF 12		
266	SF 13		
267	"BS"		
268	ACA		
269	CF 13		
270	SF 12		
271	"="		
272	ACA		
273	CF 12		
274	RCL 20		
275	ACX		
276	ADV		
277	SF 12		Print L_{ts}.
278	"L"		
279	ACA		
280	CF 12		
281	SF 13		
282	"TS"		
283	ACA		
284	CF 13		
285	SF 12		
286	"="		
287	ACA		
288	CF 12		
289	RCL 21		
290	ACX		
291	ADV		
292	ADV		
293	ADV		

Step/ Line	Key Entry	Key Code	Comments	Step/ Line	Key Entry	Key Code	Comments	Step/ Line	Key Entry	Key Code	Comments
294	GTO "PS"										
295	.END.										

Chapter 9

Support Ring Stresses

Program TI-59-9

Introduction:

TI-59-9 calculates the stresses in circular reinforcing support rings utilizing the analysis developed by Omer Blodgett and found in Design of Weldments, Section 4.7. The program calculates and prints the stress values and the support section moment of inertia, neutral axis, and affected length of the pipe wall.

Nomenclature:

Ten items are input by the user:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- P: Internal pressure (psig)
- DR: Depth of the ring (dimension along the pipe axis) (in)
- TR: Thickness of the ring (in)
- HR: Height of the ring (dimension out from pipe wall) (in)
- A: Height of point of application of the support force out from the pipe wall (in)
- F: Applied force per support point (lbs)
- N: Number of points of support (1, 2, 3, 4, 6, or 8)
- ANGL: Angle of applied force (degrees)

Three "user" keys are used to execute the program:

- A: Input data
- B: Execute program
- E: Initialize program

The program prints out the following data as output:

- e: Length of pipe wall affected (in)
- NA: Distance from outside of ring to the neutral axis of the support ring (in)
- INA: Moment of inertia about neutral axis (in)
- HOOP: Hoop stress (psi)
- TENS: Tensile stress (psi)
- BEND: Bending stress (psi)
- COMB: Total combined shear stress (psi)

Method:

TI-59-9 uses the analysis developed by Blodgett and found in detail in Design of Weldments, Section 4.7, and in Design of Welded Structures, Section 6.6. In the following, there are some excerpts from these discussions that may be used as reference. For a full understanding of the problems, the user is encouraged to study Blodgett's discussions in detail. The basic idea is that the ring and the pipe wall make up a support structure that distributes the load to lower the shell stresses in the pipe. A moment of inertia of the support structure is calculated, and with the input support force, a set of support stresses is then calculated.

Limitations:

TI-59-9 only analyzes one set of data at a time. None of the data that are input is carried over to the next analysis. The analysis only can analyze a certain set of support conditions, that is, where the number of support points on the ring is 1, 2, 3, 4, 6, or 8 points distributed equally around the ring. There is no interpolation by the program.

User Instructions

Program Number TI-59-9 **Title** Support Ring Stresses

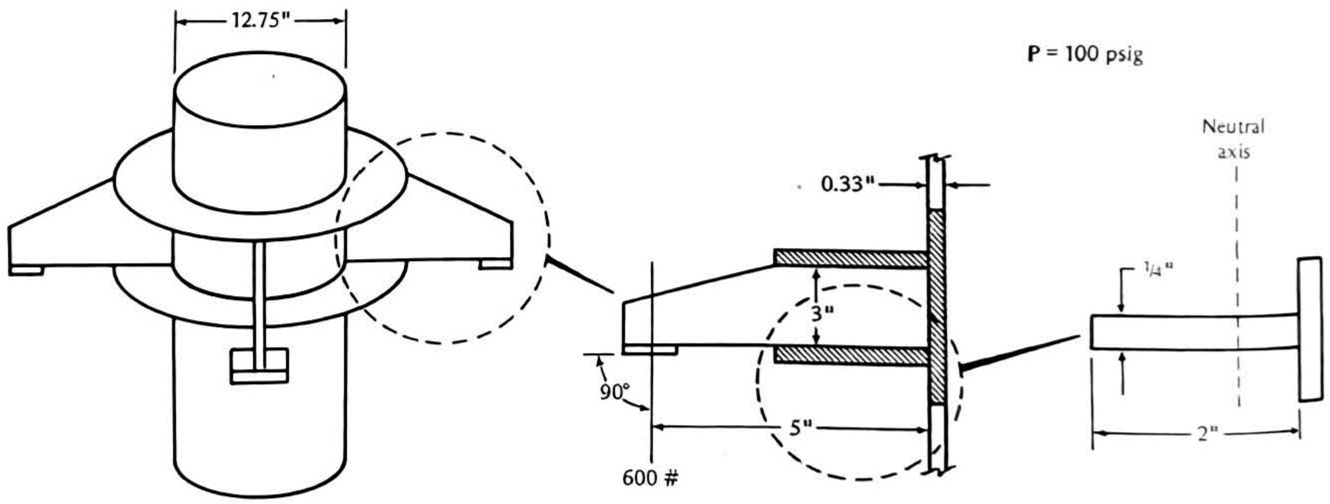
Step	Instructions	Input	Keystroke	Display
1	Initialize program.		E	0
2	Input pipe outside diameter.	OD	A	OD
3	Input pipe thickness.	T	A	T
4	Input internal pressure.	P	A	P
5	Input depth of ring.	DR	A	DR
6	Input thickness of ring.	TR	A	TR
7	Input height of ring.	HR	A	HR
8	Input height of point of application of force.	A	A	A
9	Input applied force.	F	A	F
10	Input number of points of support.	N	A	N
11	Input angle of applied force.	ANGL	A	ANGL
12	Execute program.		B	e
				NA
				INA
				STRESSES
				HOOP
				TENS
				BEND
				COMB

Data Register Contents

REGI-STER	DATA	REGI-STER	DATA
00	IND	30	
01	OD	31	500.283
02	T	32	0.318
03	P	33	289.188
04	DR	34	500.136
05	TR	35	
06	HR	36	866.089
07	A	37	1207.065
08	F	38	
09	N	39	
10	ANGL	40	
11		41	
12	HOOP	42	
13		43	
14	e	44	
15	AREA	45	
16	d	46	
17	M	47	
18	Ix	48	
19	Ina	49	
20	NA	50	
21	F1	51	
22	F2	52	
23	F'	53	
24	σct	54	
25	σcb	55	
26	σCOMB	56	
27		57	
28	d'	58	
29	mean radius	59	

Example Problem

12.75	OD	Pipe outside diameter (in)
0.33	T	Pipe wall thickness (in)
100.	P	Internal pressure (psi)
3.	DR	Depth of ring (dimension along pipe axis) (in)
0.25	TR	Thickness of ring (in)
2.	HR	Height of ring (dimension out from pipe wall) (in)
5.	A	Height of point of application of support force (in)
600.	F	Applied force (lbs)
4.	N	Number of points of support (1, 2, 3, 4, 6, or 8)
90.	ANGL	Angle of applied force (degrees)
0.716	e	Length of pipe wall affected (in)
1.613	NA	Distance from outside of ring to neutral axis (in)
1.	INA	Moment of inertia about neutral axis (in)
STRESSES		
990.	HOOP	Hoop stress (psi)
474.	TENS	Tensile stress (psi)
2577.	BEND	Bending stress (psi)
2020.	COMB	Total combined shear stress (psi)



4.7–4 / Stationary-Member Design

It should be noted that there seems to be a copying error in this sample problem. In figure 10, the value of " Cb " is noted as 1.695. Yet in the moment of inertia calculations above figure 11, the calculated value of " Cb " is 1.613. This latter value is correct, but the former value is used in the rest of the example. In the QA example of this program, this same problem is analysed. The values printed out by the calculator are those found when the " Cb " value is 1.613".

Problem 2

PART A: Four hangers are used to support a vertical 12" stand pipe, Figure 9. Determine the total radial force acting on the shell as a result of the force (P) applied to the hangers.

DATA		
p = 100 psi	P = 600 lb	a = 5 in.
r_c = 6.21 in.	θ = 90°	b = 0
t_s = .33 in.	d = 3 in.	n = 4 HANGERS

CALCULATING TENSILE STRESS IN SHELL FROM INTERNAL PRESSURE

$$\underline{\sigma_{c_p}} = \frac{pr_c}{t_s} = \frac{100 \times 6.21}{.33} = \underline{1{,}888 \text{ psi}}$$

$$\underline{\sigma_{m_p}} = \frac{pr_s}{2t_s} = \frac{100 \times 6.21}{2 \times .33} = \underline{9.42 \text{ psi}}$$

MOMENT ON SHELL SECTION FROM FORCES APPLIED TO HANGER

$$\underline{F_1} = P\cos\theta = 600 \times 0 = \underline{0 \text{ lb.}}$$

$$\underline{F_2} = P\sin\theta = 600 \times 1 = \underline{600 \text{ lb.}}$$

$$\underline{M_h} = aF_2 + bF_1 = 5 \times 600 + 0 \times 0 = \underline{3{,}000 \text{ lb}}$$

EFFECTIVE SHELL WIDTH "e" EACH SIDE OF HANGER

$$\underline{e} = \frac{\sqrt{t_s r_c}}{2} = \frac{\sqrt{.33 \times 6.21}}{2} = \underline{.72 \text{ in.}}$$

CALCULATING RADIAL FORCES APPLIED TO SHELL

$$\underline{f_a} = \frac{F_1}{d + e} = \frac{0}{3 + .72} = \underline{0 \text{ lb/in. RING OF SHELL}}$$

$$\underline{f_b} = \frac{6M}{(d+e)(d+2e)} = \frac{6 \times 3000}{(3+.72)(3+1.44)} = \underline{1{,}090 \text{ lb/in. RING}}$$

TOTAL RADIAL FORCE

$$\underline{\underline{f_1}} = f_a + f_b = 0 + 1{,}090 = \underline{\underline{1{,}090 \text{ lb/in. RING OF SHELL}}}$$

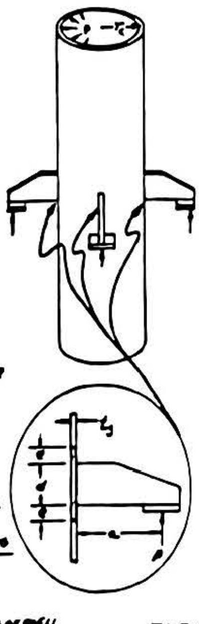


FIGURE 9

PART B: With tensile force (T) and bending moment (M_r) per 1" wide ring of this shell resulting from radial forces (f_1) applied at the four hangers, calculate the tensile (σ_{c_t}) and bending (σ_{c_b}) stresses at the hangers.

FROM TABLE I: $K_1 = 0.500$ FROM PART A: $f_1 = 1{,}090$ lb/in. RING

$$\underline{T} = K_1 f_1 = 0.500 \times 1{,}090 = \underline{545 \text{ lb/in. RING}}$$

$$\underline{A}(\text{AREA OF RING}) = Wt_s = 1 \times .33 = \underline{.33 \text{ SQ. IN}}$$

$$\underline{\sigma_{c_T}} = \frac{T}{A} = \frac{545}{.33} = \underline{1650 \text{ psi}}$$

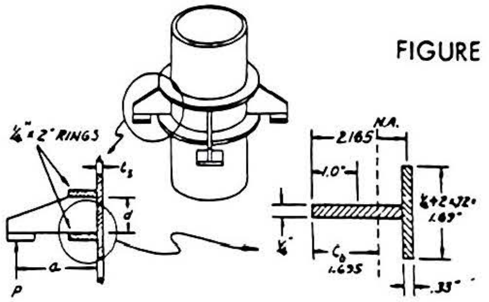
FROM TABLE I WE KNOW $\underline{M_r} = K_2 f_1 r_c = .136 \times 1090 \times 6.21 = \underline{920 \text{ in-lb.}}$

SECTION MODULUS $\underline{S} = \frac{(1)(.33)^2}{6} = \underline{.0181 \text{ in}^3}$

$$\text{THEN } \underline{\sigma_b} = \frac{M_r}{S} = \frac{920}{.0181} = \underline{50{,}800 \text{ psi}} \text{ (EXCESSIVE)}$$

Since this bending stress in the ring of the shell is excessive, it is necessary to stiffen the shell in this region. To accomplish this, two ¼" × 2" ring stiffeners are added as illustrated, Figure 10.

FIGURE 10



The effect of the bottom ring will be considered since it will apply radial tensile forces to the built-up ring and shell section. Using the method of finding moment of inertia by adding areas (Sect. 2.3), the properties of this section are as follows:

TABLE II

RING SECTION	A	d	M = Ad	I_x = Md	I_g
1.69 × .33	.557	+2.165	1.205	2.61	.005
¼ × 2.0	.500	+1.0	.500	.50	.167
TOTAL	1.057		1.705	3.282	

THEN MOMENT OF INERTIA ABOUT NEUTRAL AXIS WILL BE

$$\underline{I_{NA}} = I_x - \frac{M^2}{A} = 3.282 - \frac{1.705^2}{1.057} = \underline{0.532 \text{ in.}^4}$$

AND NEUTRAL AXIS WILL BE

$$\underline{NA} = C_b = \frac{M}{A} = \frac{1.705}{1.057} = \underline{+1.613 \text{ in.}}$$

The radial force (F) acting on the ring section and resulting from the vertical force (P) is---

$$\underline{F} = \frac{F_2 a}{d} = \frac{600 \times 5}{3} = \underline{1000 \text{ lb}}$$

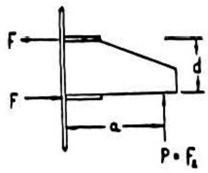


FIGURE 11

PART C: Recalculation of the tensile (σ_{ct}) and bending (σ_{cb}) stresses at the hangers yields the following results:

FROM TABLE I $K_1 = 0.500$ THE NEW F $F = 1{,}000$

$$\underline{T} = K_1 F = 0.500 \times 1{,}000 = \underline{500\ lb.}$$

$$\underline{A}\ (\text{TOTAL FROM TABLE II}) = \underline{1.057\ sq.in.}$$

$$\underline{\sigma_{cT}} = \frac{T}{A} = \frac{500}{1.057} = \underline{473\,psi}$$

FROM TABLE I WE KNOW $\underline{M_r} = K_2 F r_c = .136 \times 1{,}000 \times 6.21 = \underline{845\ in\text{-}lb.}$

$$\text{THEN } \underline{\sigma_{cb}} = \frac{M_r c}{I} = \frac{845 \times 1.695}{.532}\quad \underline{2{,}690\,psi}$$

The hoop stress of σ_{cp} = 1,888 psi in the shell will be assumed to be reduced when considered to be acting over the entire cross-section of the built-up ring section:

$$\sigma_{cp} = 1{,}888 \times \frac{\text{AREA SHELL IN RING SECTION}}{\text{AREA OF RING SECTION}}$$

$$\sigma_{cp} = 1{,}888 \times \frac{1.69 \times .33}{1.057}$$

$$\underline{\sigma_{cp}} = \underline{990\,psi}$$

Combining these stresses in the outer fiber of the lower ring, adjacent to the hanger, we find the maximum shear stress (τ_{max}) to be--

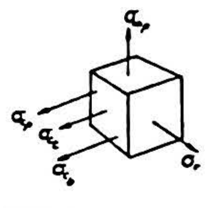


FIGURE 12

$\sigma_r = 0$

$\sigma_{mp} = 0$

NOTE: THE MERIDIAN TENSIL STRESS OF σ_m = 942 psi IN THE SHELL ONLY AND NOT IN OUTER PORTION OF LOWER RING.

$$\sigma_t = \sigma_{cp} + \sigma_{ct} + \sigma_{cb} = 990 + 473 + 2{,}690$$

$$\sigma_t = 4{,}153\,psi$$

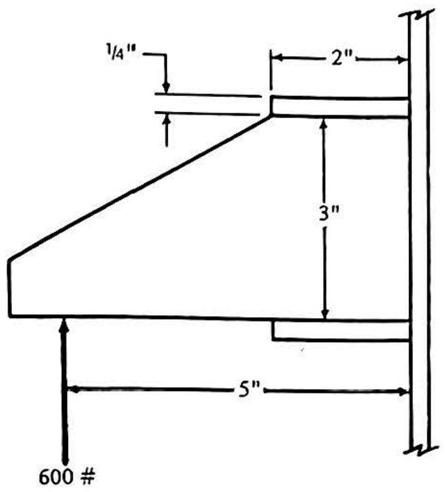
$$\underline{\tau_{max}} = \frac{4{,}153 - 0}{2} = \underline{2{,}070\,psi}$$

STRESS WITHIN REASON

DESIGN O.K.

Sample Problem

Program: TI-59-9



OD = 12.75"
T = 0.330"
P = 100 psig
N = 4

Step	Input	Key Stroke	Display	Printer		Comments
1		E	0.			Initialize program.
2	12.75	A	12.75	12.75	OD	Store pipe OD in R01.
3	.33	A	0.33	0.33	T	Store pipe T in R02.
4	100	A	100.	100.	P	Store P in R03.
5	3	A	3.	3.	DR	Store DR in R04.
6	.25	A	0.25	0.25	TR	Store TR in R05.
7	2	A	2.	2.	HR	Store HR in R06.
8	5	A	5.	5.	A	Store A in R07.
9	600	A	600.	600.	F	Store F in R08.
10	4	A	4.	4.	N	Store N in R09.
11	90	A	90.	90.	ANGL	Store ANGL in R10.
12		B	0.			
				0.716	e	Program calculates the distance from the outside of the ring to the neutral axis, the I of the ring–pipe wall area, and the length of pipe wall affected. Prints all of the above.
				1.613	NA	
				1.	INA	
				STRESSES		
				990.	HOOP	Calculates the hoop stress, tensile stress, and bending stress and combines all of the above into a maximum shear stress. Prints all of the above.
				474.	TENS	
				2577.	BEND	
				2020.	COMB	

Coding Form

Program Number TI-59-9 **Title** Support Ring Stresses

Loc	Code	Key	Comments
000	76	LBL	Input routine: Uses R00 as a pointer.
001	11	A	
002	69	OP	
003	20	20	
004	63	EX*	
005	00	00	
006	69	OP	
007	04	04	
008	73	RC*	
009	00	00	
010	69	OP	
011	06	06	
012	91	R/S	
013	76	LBL	Main program.
014	12	B	
015	43	RCL	
016	01	01	
017	75	-	Mean radius is calculated and stored in R29; e is calculated and stored in R14.
018	43	RCL	
019	02	02	
020	54	)	
021	55	÷	
022	02	2	
023	95	=	
024	42	STO	
025	29	29	
026	65	×	
027	43	RCL	
028	02	02	
029	55	÷	
030	04	4	
031	95	=	
032	34	ΓX	
033	42	STO	
034	14	14	
035	65	×	2(e) + T is stored in R28. Area of pipe wall in vicinity of ring is stored in R15.
036	02	2	
037	85	+	
038	43	RCL	
039	05	05	
040	95	=	
041	42	STO	
042	28	28	
043	65	×	
044	43	RCL	
045	02	02	
046	95	=	
047	42	STO	
048	15	15	
049	65	×	Distance from outside of ring to mean radius of pipe is stored in R16, and multiplied by the area to get area moment value. This is stored in R17.
050	53	(	
051	43	RCL	
052	02	02	
053	55	÷	
054	02	2	
055	85	+	
056	43	RCL	
057	06	06	
058	54	)	
059	42	STO	

Loc	Code	Key	Comments
060	16	16	
061	95	=	
062	42	STO	
063	17	17	
064	65	×	Transferred inertia of area is stored in R18.
065	43	RCL	
066	16	16	
067	95	=	
068	42	STO	
069	18	18	
070	43	RCL	Area of ring is summed into R15 and put into test register. Distance from outside of ring to center of ring is stored in R16.
071	05	05	
072	65	×	
073	43	RCL	
074	06	06	
075	95	=	
076	44	SUM	
077	15	15	
078	32	X:T	
079	43	RCL	
080	06	06	
081	55	÷	
082	02	2	
083	95	=	
084	42	STO	
085	16	16	
086	65	×	Area moment of ring is summed into R17. Transferred inertia of area is summed into R18.
087	32	X:T	
088	95	=	
089	44	SUM	
090	17	17	
091	65	×	
092	43	RCL	
093	16	16	
094	95	=	
095	44	SUM	
096	18	18	
097	43	RCL	Moment of inertia of area in pipe wall in the vicinity of the ring is summed into R18.
098	28	28	
099	65	×	
100	43	RCL	
101	02	02	
102	45	Y^X	
103	03	3	
104	55	÷	
105	01	1	
106	02	2	
107	95	=	
108	44	SUM	
109	18	18	
110	43	RCL	Moment of inertia of ring section is summed into R18.
111	05	05	
112	65	×	
113	43	RCL	
114	06	06	
115	45	Y^X	
116	03	3	
117	55	÷	
118	01	1	
119	02	2	

Loc	Code	Key	Comments
120	95	=	
121	44	SUM	
122	18	18	
123	43	RCL	Total moment of inertia of ring/wall cross-section is stored in R19.
124	18	18	
125	75	-	
126	43	RCL	
127	17	17	
128	33	X^2	
129	55	÷	
130	43	RCL	
131	15	15	
132	95	=	
133	42	STO	
134	19	19	
135	43	RCL	Distance from outside of ring to neutral axis is stored in R20.
136	17	17	
137	55	÷	
138	43	RCL	
139	15	15	
140	95	=	
141	42	STO	
142	20	20	
143	98	ADV	Calculated values of e, NA, and INA are printed.
144	05	5	
145	04	4	
146	69	OP	
147	04	04	
148	43	RCL	
149	14	14	
150	58	FIX	
151	03	03	
152	69	OP	
153	06	06	
154	03	3	
155	01	1	
156	01	1	
157	03	3	
158	00	0	
159	69	OP	
160	04	04	
161	43	RCL	
162	20	20	
163	69	OP	
164	06	06	
165	58	FIX	
166	00	00	
167	02	2	
168	04	4	
169	03	3	
170	01	1	
171	01	1	
172	03	3	
173	69	OP	
174	04	04	
175	43	RCL	
176	19	19	
177	69	OP	
178	06	06	
179	43	RCL	

Loc	Code	Key	Comments
180	08	08	F_1 and F_2 are calculated from F and ANGL. F_1 is stored in R21. F_2 is stored in R22.
181	32	X⇄T	
182	43	RCL	
183	10	10	
184	37	P/R	
185	42	STO	
186	22	22	
187	32	X⇄T	
188	42	STO	
189	21	21	
190	43	RCL	F′ is calculated and stored in R23.
191	22	22	
192	65	×	
193	43	RCL	
194	07	07	
195	55	÷	
196	43	RCL	
197	04	04	
198	95	=	
199	42	STO	
200	23	23	
201	43	RCL	σct is calculated using values in memory and F′. σct is stored in R24.
202	09	09	
203	85	+	
204	03	3	
205	00	0	
206	95	=	
207	42	STO	
208	00	00	
209	73	RC*	
210	00	00	
211	59	INT	
212	55	÷	
213	01	1	
214	00	0	
215	00	0	
216	00	0	
217	65	×	
218	43	RCL	
219	23	23	
220	55	÷	
221	43	RCL	
222	15	15	
223	95	=	
224	42	STO	
225	24	24	
226	73	RC*	F′ is used with the mean radius, NA and INA to calculate σcb. σcb is stored in R25.
227	00	00	
228	22	INV	
229	59	INT	
230	65	×	
231	43	RCL	
232	23	23	
233	65	×	
234	43	RCL	
235	29	29	
236	65	×	
237	43	RCL	
238	20	20	
239	55	÷	

Loc	Code	Key	Comments
240	43	RCL	
241	19	19	
242	95	=	
243	42	STO	
244	25	25	
245	43	RCL	σcp is calculated (HOOP).
246	03	03	
247	65	×	
248	43	RCL	
249	29	29	
250	55	÷	
251	43	RCL	
252	02	02	
253	65	×	
254	43	RCL	
255	28	28	
256	65	×	
257	43	RCL	
258	02	02	
259	55	÷	
260	43	RCL	
261	15	15	
262	95	=	
263	42	STO	
264	12	12	
265	69	OP	Print "STRESSES."
266	00	00	
267	03	3	
268	06	6	
269	03	3	
270	07	7	
271	03	3	
272	05	5	
273	69	OP	
274	02	02	
275	01	1	
276	07	7	
277	03	3	
278	06	6	
279	03	3	
280	06	6	
281	01	1	
282	07	7	
283	03	3	
284	06	6	
285	69	OP	
286	03	03	
287	98	ADV	
288	69	OP	
289	05	05	
290	69	OP	
291	00	00	
292	98	ADV	Print "HOOP STRESS."
293	02	2	
294	03	3	
295	03	3	
296	02	2	
297	03	3	
298	02	2	
299	03	3	

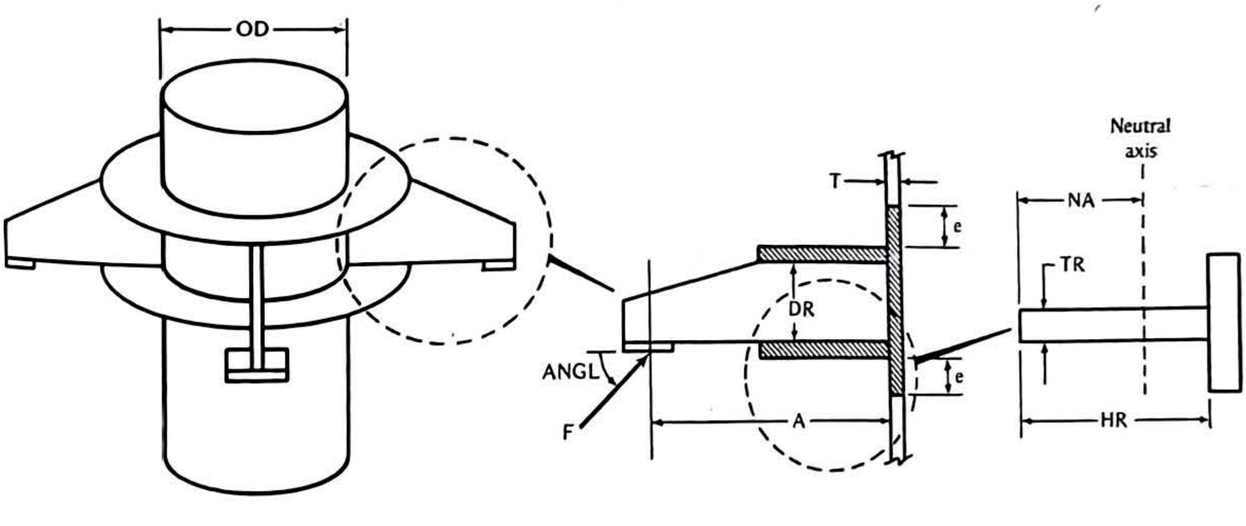
Loc	Code	Key	Comments
300	03	3	
301	69	OP	
302	04	04	
303	43	RCL	
304	12	12	
305	69	OP	
306	06	06	
307	03	3	Print "TENSILE STRESS."
308	07	7	
309	01	1	
310	07	7	
311	03	3	
312	01	1	
313	03	3	
314	06	6	
315	69	OP	
316	04	04	
317	43	RCL	
318	24	24	
319	69	OP	
320	06	06	
321	01	1	Print "BENDING STRESS."
322	04	4	
323	01	1	
324	07	7	
325	03	3	
326	01	1	
327	01	1	
328	06	6	
329	69	OP	
330	04	04	
331	43	RCL	
332	25	25	
333	69	OP	
334	06	06	
335	01	1	Print combined stress combining σcb, σct, and Hoop stresses.
336	05	5	
337	03	3	
338	02	2	
339	03	3	
340	00	0	
341	01	1	
342	04	4	
343	69	OP	
344	04	04	
345	43	RCL	
346	12	12	
347	85	+	
348	43	RCL	
349	24	24	
350	85	+	
351	43	RCL	
352	25	25	
353	95	=	
354	55	÷	
355	02	2	
356	95	=	
357	42	STO	
358	26	26	
359	69	OP	

Loc	Code	Key	Comments
360	06	06	
361	98	ADV	Advance paper.
362	98	ADV	
363	98	ADV	
364	98	ADV	
365	76	LBL	Initialize program.
366	15	E	
367	22	INV	
368	58	FIX	Clear all memories.
369	47	CMS	
370	29	CP	
371	03	3	Float decimal point.
372	02	2	
373	01	1	
374	06	6	
375	42	STO	
376	01	01	Load registers with alpha codes for input routine.
377	03	3	
378	07	7	
379	42	STO	
380	02	02	
381	03	3	
382	03	3	
383	42	STO	
384	03	03	
385	01	1	
386	06	6	
387	03	3	
388	05	5	
389	42	STO	
390	04	04	
391	03	3	
392	07	7	
393	03	3	
394	05	5	
395	42	STO	
396	05	05	
397	02	2	
398	03	3	
399	03	3	
400	05	5	
401	42	STO	
402	06	06	
403	01	1	
404	03	3	
405	42	STO	
406	07	07	
407	02	2	
408	01	1	
409	42	STO	
410	08	08	
411	03	3	
412	01	1	
413	42	STO	
414	09	09	
415	01	1	
416	03	3	
417	03	3	
418	01	1	
419	02	2	
420	02	2	
421	02	2	
422	07	7	
423	42	STO	
424	10	10	
425	93	.	Load registers with constants, K_1 and K_2.
426	03	3	
427	01	1	
428	08	8	
429	42	STO	
430	32	32	
431	02	2	
432	08	8	
433	09	9	
434	93	.	
435	01	1	
436	08	8	
437	08	8	
438	42	STO	
439	33	33	
440	05	5	
441	00	0	
442	00	0	
443	93	.	
444	01	1	
445	03	3	
446	06	6	
447	42	STO	
448	34	34	
449	08	8	
450	06	6	
451	06	6	
452	93	.	
453	00	0	
454	08	8	
455	09	9	
456	42	STO	
457	36	36	
458	01	1	
459	02	2	
460	00	0	
461	07	7	
462	93	.	
463	00	0	
464	06	6	
465	05	5	
466	42	STO	
467	38	38	
468	05	5	
469	00	0	
470	00	0	
471	93	.	
472	02	2	
473	08	8	
474	03	3	
475	42	STO	
476	31	31	
477	25	CLR	
478	91	R/S	

Pipe outside diameter (in)
Pipe wall thickness (in)
Internal pressure (psi)
Depth of ring (dimension along pipe axis) (in)
Thickness of ring (in)
Height of ring (dimension out from pipe wall) (in)
Height of point of application of support force (in)
Applied force (lbs)
Number of points of support (1, 2, 3, 4, 6, or 8)
Angle of applied force (degrees)

Length of pipe wall affected (in)
Distance from outside of ring to neutral axis (in)
Moment of inertia about neutral axis (in)

Hoop stress (psi)
Tensile stress (psi)
Bending stress (psi)
Total combined shear stress (psi)



Program HP-41CV-9: Support Ring Stresses

Introduction:

HP-41CV-9 calculates the stresses in circular reinforcing support rings utilizing the analysis developed by Omer Blodgett and found in Design of Weldments, section 4.7. The program calculates and prints the stress values and the support section moment of inertia, neutral axis, and affected length of the pipe wall.

Nomenclature:

Ten items are input by the user:

- OD: Pipe outside diameter (in)
- T: Pipe wall thickness (in)
- P: Internal pressure (psig)
- DR: Depth of the ring (dimension along the pipe axis) (in)
- TR: Thickness of the ring (in)
- HR: Height of the ring (dimension out from the pipe wall) (in)
- A: Height of point of application of the support force out from the pipewall (in)
- F: Applied force per support point (lbs)
- N: Number of points of support (1, 2, 3, 4, 6, or 8)
- ∡: Angle of applied force (degrees)

Two "user" keys are used to execute the program:

- E: Initialize program (LN in USER mode)
- R/S: Used to input data

The program prints out the following data as output:

- e: Length of pipe wall affected (in)
- NA: Distance from outside of ring to the neutral axis of the support ring (in)
- INA: Moment of inertia about neutral axis (in^4)
- σ hoop: Hoop stress (psi)
- σ tens: Tensile stress (psi)
- σ bend: Bending stress (psi)
- τ comb: Total combined shear stress (psi)

Method:

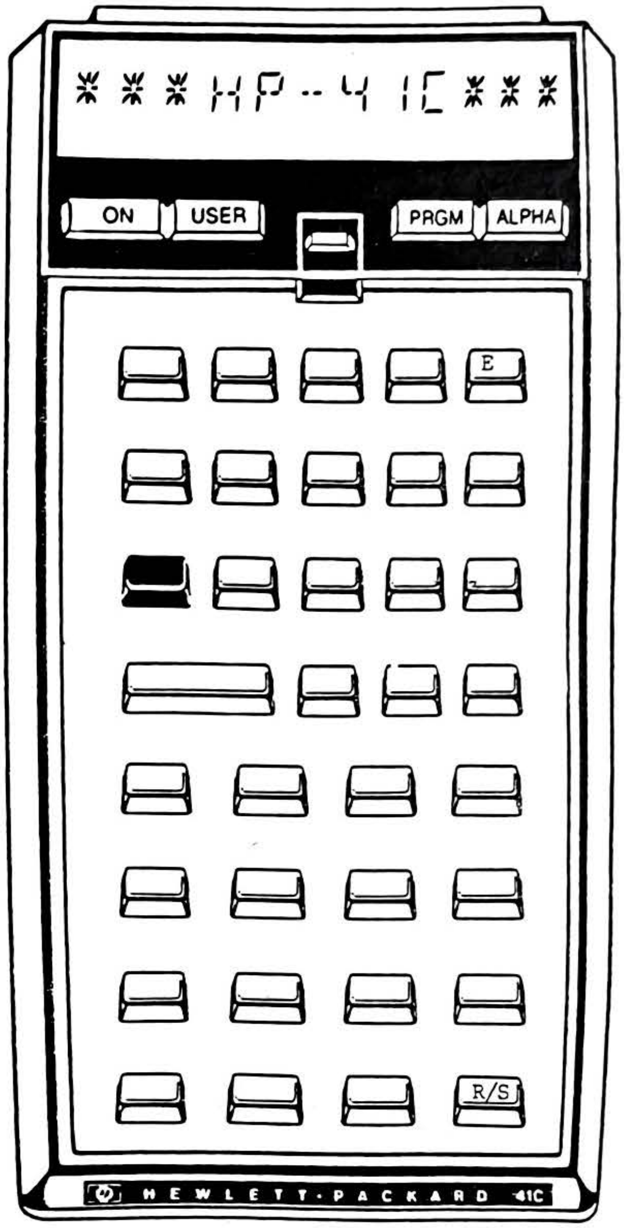
HP-41CV-9 uses the analysis developed by Blodgett and can be found in detail in Design of Weldments, Section 4.7, and in Design of Welded Structures, Section 6.6. In the following, there are some excerpts from these discussions that may be used as reference. For a full understanding of the problem the user is encouraged to study Blodgett's discussions in detail. The basic idea is that the ring and the pipe wall make up a support structure that distribute the load to lower the shell stresses in the pipe. A moment of inertia of the support structure is calculated, and with the input support force, a sèt of support stresses is then calculated.

Limitations:

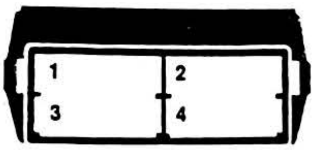
HP-41CV-9 only analyzes one set of data at a time. None of the data that are input is carried over to the next analysis. The analysis only can analyze a certain set of support conditions, that is, where the number of support points on the ring is 1, 2, 3, 4, 6, or 8 points, distributed equally around the ring. There is no interpolation by the program.

Keyboard Card Labeling

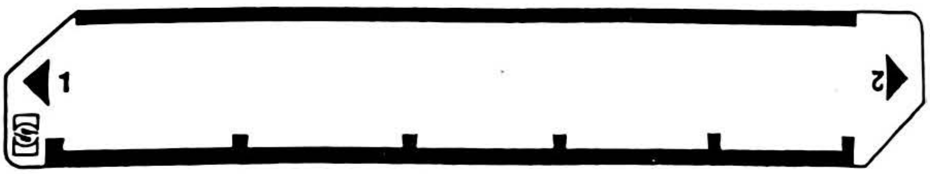
KEYBOARD



SYSTEM CONFIGURATION



CARD



User Instructions

Program Number HP-41VC-9 **Title** Support Ring Stresses

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards.		E	OD=
2	Input OD.	OD	R/S	T=
3	Input T.	T	R/S	P=
4	Input P.	P	R/S	DR=
5	Input DR.	DR	R/S	TR=
6	Input TR.	TR	R/S	HR=
7	Input HR.	HR	R/S	A=
8	Input A.	A	R/S	F=
9	Input F.	F	R/S	N=
10	Input N.	N	R/S	∡=
11	Input ∡.	∡	R/S	
				e
				NA
				INA
				STRESSES
				σ hoop
				σ tens
				σ bend
				τ comb

Registers, Flags, Assignments

Program Number HP-41CV-9 **Title** Support Ring Stresses

DATA REGISTERS

00	
01	OD
02	T
03	P
04	DR
05	TR
06	HR
07	A
08	F
09	N
10	∡
11	
12	Hoop stress
13	
14	e
15	Pipe area
16	d
17	M
18	Ix
19	INA
20	NA
21	f1
22	f2
23	F'
24	tens
25	bend
26	comb
27	
28	d'
29	rm
30	
31	
32	
33	
34	
35	
36	
37	
38	

DATA REGISTERS

39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates

ASSIGNMENTS

Label	Key	Function	Key
RNG	E (15)		

```
OD= 12.750
T= 0.330
P= 100.000
DR= 3.000
TR= 0.250
HR= 2.000
A= 5.000
F= 600.000
N= 4.000
∠= 90.000

          e=0.716
         NA=1.613
        INA=0.529

   STRESSES

        σhoop=990.
        σtens=474.
      σbend=2,577.

      τcomb=2,020.
```

4.7–4 / Stationary-Member Design

It should be noted that there seems to be a copying error in this sample problem. In figure 10, the value of " Cb " is noted as 1.695. Yet in the moment of inertia calculations above figure 11, the calculated value of " Cb " is 1.613. This latter value is correct, but the former value is used in the rest of the example. In the QA example of this program, this same problem is analysed. The values printed out by the calculator are those found when the " Cb " value is 1.613".

Problem 2

PART A: Four hangers are used to support a vertical 12" stand pipe, Figure 9. Determine the total radial force acting on the shell as a result of the force (P) applied to the hangers.

DATA		
$p = 100$ psi	$P = 600$ lb	$a = 5$ in.
$r_c = 6.21$ in.	$\theta = 90°$	$b = 0$
$t_s = .33$ in.	$d = 3$ in.	$n = 4$ HANGERS

CALCULATING TENSILE STRESS IN SHELL FROM INTERNAL PRESSURE

$$\sigma_{c_p} = \frac{p r_c}{t_s} = \frac{100 \times 6.21}{.33} = \underline{1,888 \text{ psi}}$$

$$\sigma_{m_p} = \frac{p r_c}{2 t_s} = \frac{100 \times 6.21}{2 \times .33} = \underline{942 \text{ psi}}$$

MOMENT ON SHELL SECTION FROM FORCES APPLIED TO HANGER

$$F_1 = P\cos\theta = 600 \times 0 = \underline{0 \text{ lb.}}$$

$$F_2 = P\sin\theta = 600 \times 1 = \underline{600 \text{ lb.}}$$

$$M_h = aF_2 + bF_1 = 5 \times 600 + 0 \times 0 = \underline{3,000 \text{ in-lb}}$$

EFFECTIVE SHELL WIDTH "e" EACH SIDE OF HANGER

$$e = \frac{\sqrt{t_s r_c}}{2} = \frac{\sqrt{.33 \times 6.21}}{2} = \underline{.72 \text{ in.}}$$

CALCULATING RADIAL FORCES APPLIED TO SHELL

$$f_a = \frac{F_1}{d + e} = \frac{0}{3 + .72} = \underline{0 \text{ lb/in ring of shell}}$$

$$f_b = \frac{6M}{(d+e)(d+2e)} = \frac{6 \times 3000}{(3+.72)(3+1.44)} = \underline{1,090 \text{ lb/in. ring}}$$

TOTAL RADIAL FORCE

$$f_1 = f_a + f_b = 0 + 1,090 = \underline{\underline{1,090 \text{ lb/in. ring of shell}}}$$

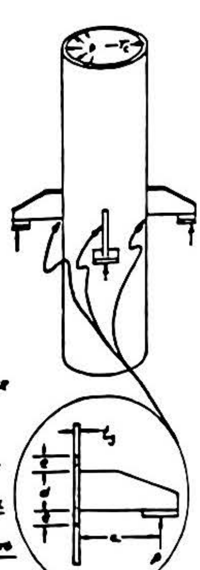


FIGURE 9

PART B: With tensile force (T) and bending moment (M_r) per 1" wide ring of this shell resulting from radial forces (f_1) applied at the four hangers, calculate the tensile (σ_{c_t}) and bending (σ_{c_b}) stresses at the hangers.

FROM TABLE I: $K_1 = 0.500$ FROM PART A: $f_1 = 1,090$ lb/in. ring

$$T = K_1 f_1 = 0.500 \times 1,090 = \underline{545 \text{ lb/in. ring}}$$

$$A (\text{area of ring}) = W t_s = 1 \times .33 = \underline{.33 \text{ sq. in.}}$$

$$\sigma_{c_T} = \frac{T}{A} = \frac{545}{.33} = \underline{1650 \text{ psi}}$$

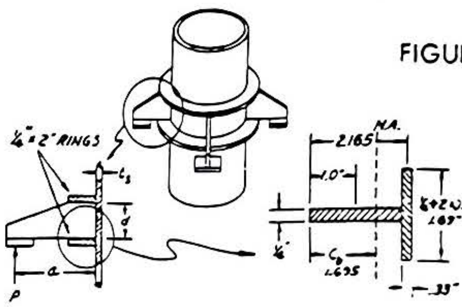
FROM TABLE I WE KNOW $M_r = K_2 f_1 r_c = .136 \times 1,090 \times 6.21 = \underline{920 \text{ in-lb.}}$

SECTION MODULUS $S = \frac{(1)(.33)^2}{6} = \underline{.0181 \text{ in}^3}$

$$\text{THEN } \sigma_{c_b} = \frac{M_r}{S} = \frac{920}{.0181} = \underline{50,800 \text{ psi}} \text{ (EXCESSIVE)}$$

Since this bending stress in the ring of the shell is excessive, it is necessary to stiffen the shell in this region. To accomplish this, two ¼" × 2" ring stiffeners are added as illustrated, Figure 10.

FIGURE 10



The effect of the bottom ring will be considered since it will apply radial tensile forces to the built-up ring and shell section. Using the method of finding moment of inertia by adding areas (Sect. 2.3), the properties of this section are as follows:

TABLE II

RING SECTION	A	d	$M = Ad$	$I_x = Md$	I_g
$1.69 \times .33$	.557	+2.165	1.205	2.61	.005
$\frac{1}{4} \times 2.0$	.500	+1.0	.500	.50	.167
TOTAL	1.057		1.705	3.282	

THEN MOMENT OF INERTIA ABOUT NEUTRAL AXIS WILL BE

$$I_{NA} = I_x - \frac{M^2}{A} = 3.282 - \frac{1.705^2}{1.057} = \underline{0.532 \text{ in.}^4}$$

AND NEUTRAL AXIS WILL BE

$$NA = C_b = \frac{M}{A} = \frac{1.705}{1.057} = \underline{+1.613 \text{ in.}}$$

The radial force (F) acting on the ring section and resulting from the vertical force (P) is---

$$\underline{F} = \frac{F_2 a}{d} = \frac{600 \times 5}{3} = \underline{1000 \text{ lb}}$$

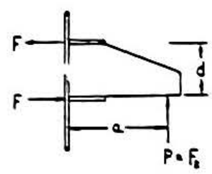


FIGURE 11

PART C: Recalculation of the tensile (σ_{c_t}) and bending (σ_{c_b}) stresses at the hangers yields the following results:

FROM TABLE I $K_1 = 0.500$ THE NEW F $F = 1,000$

$$\underline{T} = K_1 F = 0.500 \times 1,000 = \underline{500\text{ lb.}}$$

$$\underline{A}\ (\text{TOTAL FROM TABLE II}) = \underline{1.057\text{ sq.in.}}$$

$$\underline{\sigma_{c_T}} = \frac{T}{A} = \frac{500}{1.057} = \underline{473\text{ psi}}$$

FROM TABLE I WE KNOW $\underline{M_r} = K_2 F r_c = .136 \times 1,000 \times 6.21 = \underline{845\text{ in-lb.}}$

$$\text{THEN } \underline{\sigma_{c_b}} = \frac{M_r c}{I} = \frac{845 \times 1.695}{.532} \quad \underline{2,690\text{ psi}}$$

The hoop stress of $\sigma_{c_p} = 1,888$ psi in the shell will be assumed to be reduced when considered to be acting over the entire cross-section of the built-up ring section:

$$\sigma_{c_p} = 1,888 \times \frac{\text{AREA SHELL IN RING SECTION}}{\text{AREA OF RING SECTION}}$$

$$\sigma_{c_p} = 1,888 \times \frac{1.69 \times .33}{1.057}$$

$$\underline{\sigma_{c_p}} = \underline{990\text{ psi}}$$

Combining these stresses in the outer fiber of the lower ring, adjacent to the hanger, we find the maximum shear stress (τ_{max}) to be--

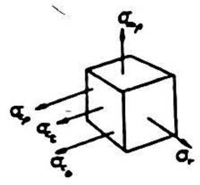


FIGURE 12

$\sigma_r = 0$

$\sigma_{m_p} = 0$

NOTE: THE MERIDIAN TENSIL STRESS OF $\sigma_m = 942$ psi IN THE SHELL ONLY AND NOT IN OUTER PORTION OF LOWER RING.

$$\sigma_c = \sigma_{c_p} + \sigma_{c_t} + \sigma_{c_b} = 990 + 473 + 2,690$$

$$\sigma_c = 4,153\text{ psi}$$

$$\underline{\tau_{max}} = \frac{4,153 - 0}{2} = \underline{2,070\text{ psi}}$$

STRESS WITHIN REASON

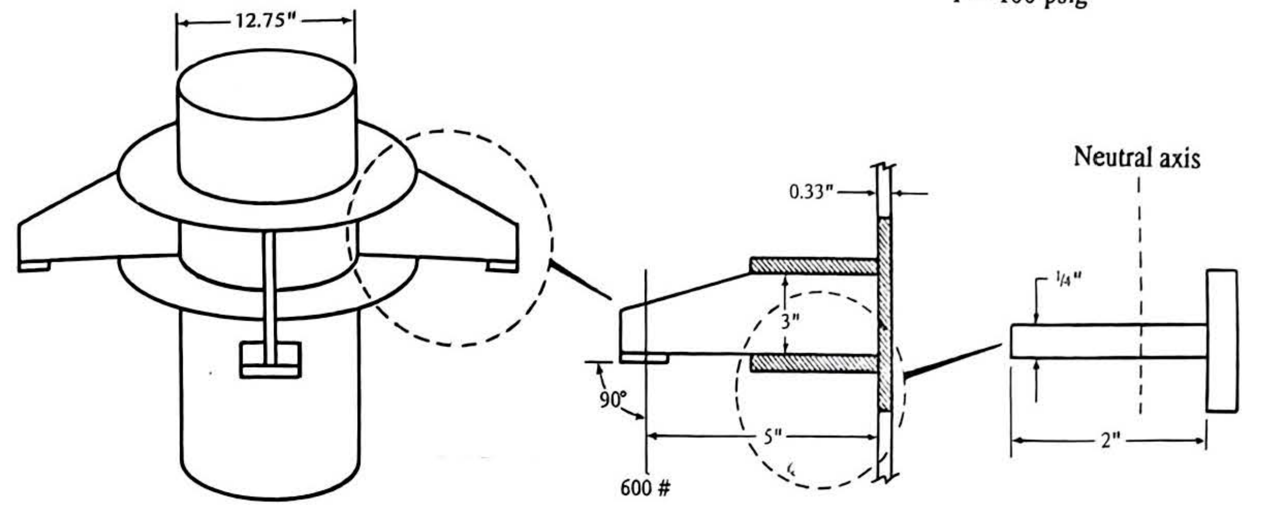
DESIGN O.K.

Sample Problem

Program: HP-41CV-9 Title Support Ring Stresses

Sample Problem (Sketch if Desired)

P = 100 psig



Input	Function	Display	Comments
	E	OD=	Initializes program, prompts for OD.
12.75	R/S	T=	Stores OD in R01; prompts for T.
.33	R/S	P=	Stores T in R02; prompts for P.
100	R/S	DR=	Stores P in R03; prompts for DR.
3	R/S	TR=	Stores DR in R04; prompts for TR.
.25	R/S	HR=	Stores TR in R05; prompts for HR.
2	R/S	A=	Stores HR in R06; prompts for A.
5	R/S	F=	Stores A in R07; prompts for F.
600	R/S	N=	Stores F in R08; prompts for N.
4	R/S	∡=	Stores N in R09; prompts for ∡.
90	R/S		Stores ∡ in R10.
		e = 0.716 NA = 1.613 INA = 0.529	The program first determines the moment of inertia of the support structure and finds the distance from the outside edge of the ring to the neutral axis. Then the length of wall that is affected on either side of the ring is calculated.
		STRESSES	These three pieces of data are printed.
		σhoop = 990. σtens = 474. σbend = 2,577. τcomb = 2,020.	Then the program calculates the stresses in the ring from the input values of force and angle, the shape coefficients that are stored in memory, and the moment of inertia data that was calculated earlier. These stresses are then printed.

Coding Form

Program Number HP-41CV-9 Title Support Ring Stresses

Step/Line	Key Entry	Key Code	Comments
01	♦LBL "RNG"		Initialize program. Clear all registers, load R31, 32, 33, 34, 36, and 38 with data from Table I.
02	CLRG		
03	500.283		
04	STO 31		
05	.318		
06	STO 32		
07	289.188		
08	STO 33		
09	500.136		
10	STO 34		
11	866.089		
12	STO 36		
13	1207.065		
14	STO 38		
15	1.01		Set pointer.
16	STO 00		
17	"OD"		Load alpha labels in R01–R10.
18	ASTO 01		
19	"T"		
20	ASTO 02		
21	"P"		
22	ASTO 03		
23	"DR"		
24	ASTO 04		
25	"TR"		
26	ASTO 05		
27	"HR"		
28	ASTO 06		
29	"A"		
30	ASTO 07		
31	"F"		
32	ASTO 08		
33	"N"		
34	ASTO 09		
35	"∡"		
36	ASTO 10		
37	FIX 3		Input routine. Uses R00 a pointer and a counter.
38	♦LBL A		
39	CLA		
40	ARCL IND 00		
41	"⊢="		
42	SF 12		
43	PROMPT		
44	ACA		
45	CF 12		
46	ACX		
47	PRBUF		
48	STO IND 00		When all data is input, the main routine starts.
49	ISG 00		
50	GTO A		
51	ADV		Main routine. Mean radius is calculated and stored in R29.
52	RCL 01		
53	RCL 02		
54	-		
55	2		
56	/		
57	STO 29		
58	RCL 02		e is stored in R14.
59	*		
60	4		
61	/		
62	SQRT		
63	STO 14		
64	2		d′ (length of pipe wall affected on either side of ring) is stored in R28.
65	*		
66	RCL 05		
67	+		
68	STO 28		
69	RCL 02		Area of pipe wall stored in R15.
70	*		
71	STO 15		
72	RCL 02		Distance from outside of ring to mean radius is stored in R16.
73	2		
74	/		
75	RCL 06		
76	+		
77	STO 16		
78	*		Area moment is stored in R17.
79	STO 17		
80	RCL 16		Transferred area inertia is stored in R18.
81	*		
82	STO 18		
83	RCL 05		Area of ring summed into R15.
84	RCL 06		
85	*		
86	ST+ 15		
87	RCL 06		Distance from ℄ of ring to outside of ring stored in R16.
88	2		
89	/		
90	STO 16		
91	*		Area moment summed into R17.
92	ST+ 17		
93	RCL 16		Transferred area inertia summed into R18.
94	*		
95	ST+ 18		
96	RCL 28		Moment of inertia of ring/wall section calculated and summed into R18.
97	RCL 02		
98	3		
99	Y↑X		
100	*		
101	12		
102	/		
103	ST+ 18		
104	RCL 05		Moment of inertia of ring section calculated and summed into R18.
105	RCL 06		
106	3		
107	Y↑X		
108	*		
109	12		
110	/		
111	ST+ 18		
112	RCL 18		Moment of inertia of support section is calcualted and stored in R19 (INA).
113	RCL 17		
114	X↑2		
115	RCL 15		
116	/		
117	-		
118	STO 19		
119	RCL 17		Distance from outside of ring to neutral axis is stored in R20 (NA).
120	RCL 15		
121	/		
122	STO 20		
123	"e="		"e", "NA", and "INA" are printed.
124	ARCL 14		
125	ACA		
126	ADV		
127	"NA="		
128	ARCL 20		
129	ACA		
130	ADV		
131	"INA="		
132	ARCL 19		
133	ACA		
134	ADV		
135	ADV		
136	RCL 10		f1 and f2 are calculated using F and ∡. f1 is stored in R21; f2 is stored in R22.
137	RCL 08		
138	P-R		
139	STO 21		
140	X<>Y		
141	STO 22		
142	RCL 07		
143	*		
144	RCL 04		
145	/		
146	STO 23		Pointer to data in memory is
147	30		

Step/Line	Key Entry	Key Code	Comments
148	RCL 09		determined and stored in R00.
149	+		
150	STO 00		
151	RCL IND 00		K_1 is decoded from memory and used to calculate the tensile stress σ tens is stored in R24.
152	INT		
153	1000		
154	/		
155	RCL 23		
156	*		
157	RCL 15		
158	/		
159	STO 24		
160	RCL IND 00		K_2 is decoded from memory and used to calculate the bending stress. σ bend is stored in R25.
161	FRC		
162	RCL 23		
163	*		
164	RCL 29		
165	*		
166	RCL 20		
167	*		
168	RCL 19		
169	/		
170	STO 25		
171	RCL 03		Hoop stress is calculated and stored in R12.
172	RCL 29		
173	*		
174	RCL 28		
175	*		
176	RCL 15		
177	/		
178	STO 12		
179	"STRESSES"		Print "STRESSES."
180	SF 12		
181	FMT		
182	ACA		
183	PRBUF		
184	FIX 0		Print hoop stress.
185	ADV		
186	9		
187	SF 12		
188	ACCHR		
189	CF 12		
190	SF 13		
191	"HOOP="		
192	ARCL 12		
193	ACA		
194	ADV		
195	9		Print tensile stress.
196	SF 12		
197	ACCHR		
198	CF 12		
199	"TENS="		
200	ARCL 24		
201	ACA		
202	ADV		
203	9		Print bending stress.
204	SF 12		
205	ACCHR		
206	CF 12		
207	"BEND="		
208	ARCL 25		
209	ACA		
210	ADV		
211	ADV		Calculate and print combined shear stress.
212	14		
213	SF 12		
214	ACCHR		
215	CF 12		
216	"COMB="		
217	RCL 12		
218	RCL 24		
219	RCL 25		
220	+		
221	+		
222	2		
223	/		
224	STO 26		
225	ARCL 26		
226	ACA		
227	ADV		
228	ADV		Reinitialize.
229	ADV		
230	CF 13		
231	GTO "RNG"		
232	END		

Internal Pressure

Chapter **10**

Pressure Reinforcing Pads per ASME/ANSI B31.3

Program TI-59-10

Introduction:

TI-59-10 performs calculations set out in ASME/ANSI B31.3, 1980, to determine the need for and the dimensions of the reinforcing pad needed to contain internal pressure at a stub-in connection. The program prints out all of the relevant data, such as reinforcing zone dimensions and required area to be replaced and the thickness and width of the required pad, or the message "NO PAD" if there is sufficient area in the header and branch for pressure containment.

Nomenclature:

Sixteen pieces of data are needed to execute the program:

- H OD: Header outside diameter (in)
- HT: Header nominal or purchased wall thickness (in)
- HPSI: Design pressure for the header (psig)
- SMAX: Allowable stress for the header (psi)
- HCOR: Corrosion allowance for the header (in)
- HDEG: Design temperature for the header (°F)
- SMLS: Fabrication code for the header
  0 = Plate-fabricated pipe
  1 = Seamless pipe
- B OD: Branch outside diameter (in)
- BT: Branch nominal or purchased wall thickness (in)
- BPSI: Design pressure for the branch (psig)
- SMAX: Allowable stress for the branch (psi)
- BCOR: Corrosion allowance for the branch (in)
- BDEG: Design temperature for the branch (°F)
- SMLS: Fabrication code for the branch (see above)
- MATL: Material code for the connection
  1 = Ferritic steel
  2 = Austenitic steel
  3 = Other ductile materials
  4 = Cast iron
- ANGL: Angle of intersection of the branch and header (degrees)

The program calculates the following data:

- HT′: Nominal wall thickness of the header less mill tolerance and corrosion allowance (in)
- BT′: Same as above for the branch (in)
- H-3A: Minimum wall thickness of the header according to equation 3A of ANSI B31.3, Section 304.1.2 (in)
- B-3A: Minimum wall thickness for the branch (in)
- D1: Effective length removed from pipe at branch (in)
- D2: "Half-width" of reinforcement zone (in)
- AR: (A1) Reinforcement area required (in^2)
- L4: Height of reinforcement zone outside of run pipe (in)
- AH: (A2) Excess area in the header wall (in^2)
- AB: (A3) Excess area in the branch wall (in^2)
- AA: Area available for reinforcement (AH + AB)
- THCK: Pad thickness (in)
- WIDE: Pad width (in)

Method:

TI-59-10 performs all the calculations set forth in ASME/ANSI B31.3 1980, Section 304.3.3. First, the corrosion allowance and the mill tolerance is removed from the input values of nominal branch thickness and header

thickness. Mill tolerance for seamless pipe is 12½ percent. For pipe fabricated from plate, mill tolerance is .01 in. The value to be used is decided by the user during input. Then the program calculates the minimum wall thickness needed to contain internal pressure, using Equation 3A in Section 304.1.2 of ANSI B31.3, 1980, for both header and branch.* Using these values and the other input data, the program determines the area needed for pressure containment, the area available in the header and branch walls, and the dimensions of the reinforcement zone. If the area available is greater than the area required, the program prints the message "NO PAD." If the area available is insufficient, the program starts with a pad thickness of .125 in. and computes the pad width. If the width falls within the reinforcement zone width, the program prints the pad dimensions. If not, the pad thickness is increased by .0625 in. and the process starts again.

There are two points the user should understand about the assumptions the program makes.

1. The program assumes no excess weld credit.
2. The program assumes that Tr is always zero when calculating the value of L4.

Limitations:

TI-59-10 performs one branch connection at a time. No data are carried over from one execution to another. The program is self-initializing. After the initial run, the program initializes itself. The equations used are not applicable for pipes under external pressure. There is no check of the limits of the thickness the pad may be. There is also no way to calculate a branch connection made up of different materials.

*The value of Y used in Equation 3A is determined by the program, using the input values of HDEG and BDEG. When necessary, Y is interpolated between the two values found in Section 304.1.2.

User Instructions

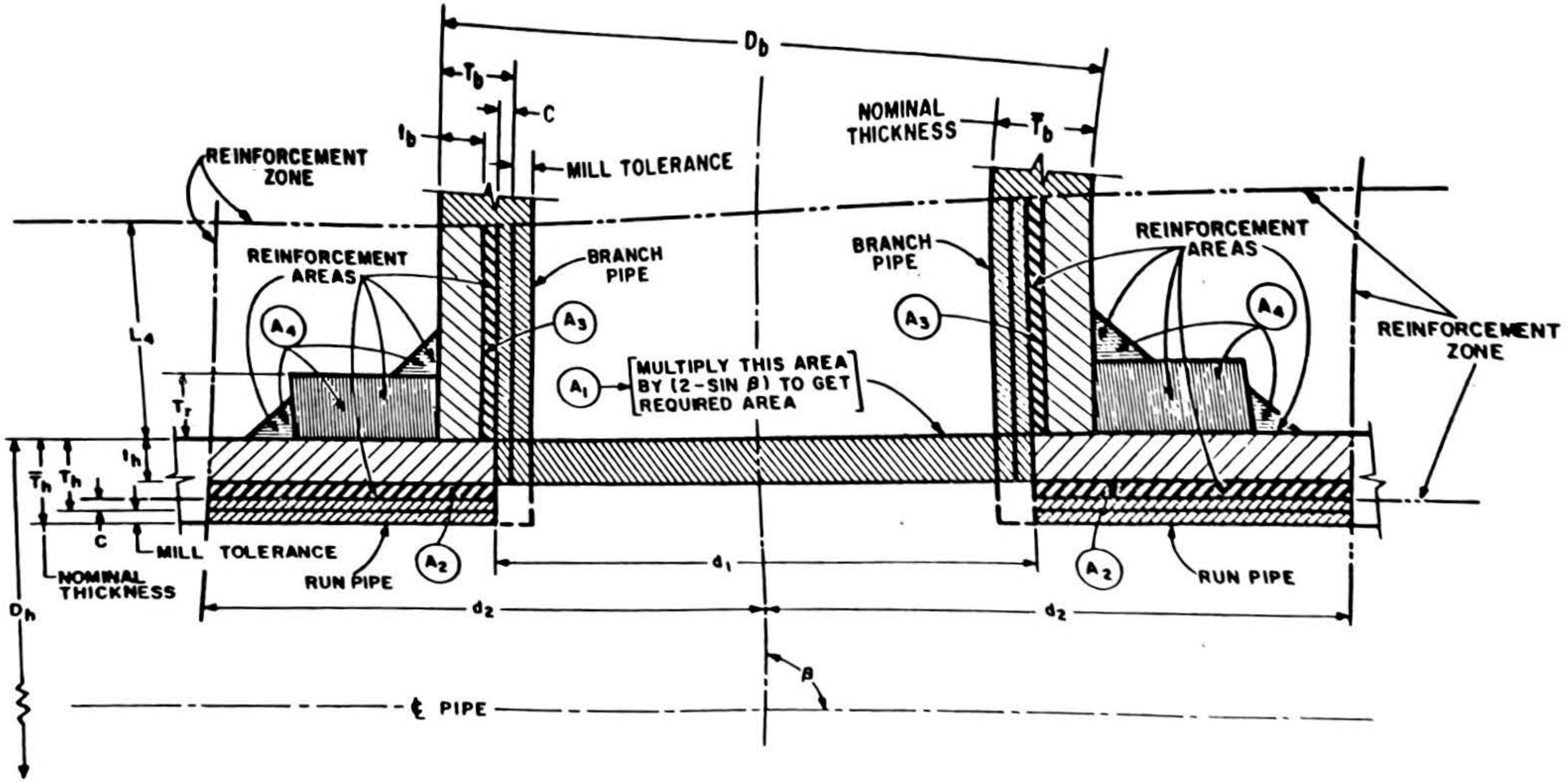
Program Number TI-59-10 **Title** Pressure Reinforcing Pads

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards (3).		CLR	1, 2, or 3
2	Initialize program.		E	0
3	Input header outside diameter.	H OD	A	H OD
4	Input header thickness.	HT	A	HT
5	Input header design pressure.	HPSI	A	HPSI
6	Input header allowable stress.	SMAX	A	SMAX
7	Input header corrosion allowance.	HCOR	A	HCOR
8	Input header design temperature.	HDEG	A	HDEG
9	Input header seamless flag.	SMLS	A	SMLS
10	Input branch outside diameter.	B OD	A	B OD
11	Input branch thickness.	BT	A	BT
12	Input branch design pressure.	BPSI	A	BPSI
13	Input branch allowable stress.	SMAX	A	SMAX
14	Input branch corrosion allowance.	BCOR	A	BCOR
15	Input branch design temperature.	BDEG	A	BDEG
16	Input branch seamless flag.	SMLS	A	SMLS
17	Input material code for junction.	MATL	A	MATL
18	Input intersection angle.	ANGL	A	ANGL
19	Execute program.		B	
				HT '
				BT '
				H-3A
				B-3A
				D1
				D2
				AR
				L4
				AH
				AB
				AA
				THICK
				WIDE
				(or)
				NO PAD

Data Register Contents

REGISTER	DATA	REGISTER	DATA
00	DSZ	30	23003216 "H OD"
01	H OD	31	2337 "HT"
02	HT	32	23333624 "HPSI"
03	HPSI	33	36301344 "SMAX"
04	SMAX	34	23153235 "HCOR"
05	HCOR	35	23161722 "HDEG"
06	HDEG	36	36302736 "SMLS"
07	SMLS	37	14003216 "B OD"
08	B OD	38	1437 "BT"
09	BT	39	14333624 "BPSI"
10	BPSI	40	36301344 "SMAX"
11	SMAX	41	14153235 "BCOR"
12	BCOR	42	14161722 "BDEG"
13	BDEG	43	36302736 "SMLS"
14	SMLS	44	30133736 "MATL"
15	MATL	45	13312227 "ANGL"
16	ANGL	46	233765 "HT'"
17	HT'	47	143765 "BT'"
18	BT'	48	23200413 "H-3A"
19	H-3A	49	14200413 "B-3A"
20	B-3A	50	1602 "D1"
21	D1	51	1603 "D2"
22	D2	52	1335 "AR"
23	AR	53	2705 "L4"
24	L4	54	1323 "AH"
25	AH	55	1314 "AB"
26	AB	56	1313 "AA"
27	AA	57	37271526 "THCK"
28	THCK	58	43241617 "WIDE"
29	WIDE	59	Various data

The alpha codes in R30-R58 are stored on magnetic card side 3.



NOTE: THIS FIGURE ILLUSTRATES THE NOMENCLATURE OF 304.3.3. IT DOES NOT INDICATE COMPLETE WELDING DETAILS OR A PREFERRED METHOD OF CONSTRUCTION. FOR TYPICAL WELD DETAILS, SEE FIGURE 327.4.4D.

(a)

FIG. 304.3.3 BRANCH CONNECTION NOMENCLATURE

304.3.3 Reinforcement of Welded Branch Connections. Added reinforcement is required to meet the criteria in 304.3.3(b) and (c) when it is not provided inherently in the components of the branch connection. Sample problems illustrating the calculations for branch reinforcement are shown in Appendix H.

(a) *Nomenclature.* The nomenclature below is used in the pressure design of branch connections. It is illustrated in Fig. 304.3.3, which does not indicate details for construction or welding. Some of the terms defined in Appendix J are subject to further definitions or variations, as follows:

b = subscript referring to branch

d_1 = effective length removed from pipe at branch

d_2 = "half width" of reinforcement zone
= d_1 or $(T_b - c) + (T_h - c) + d_1/2$, whichever is greater, but in any case not more than D_h

h = subscript referring to run or header

L_4 = height of reinforcement zone outside of run pipe
= $2.5(T_h - c)$ or $2.5(T_b - c) + T_r$, whichever is less

T_r = minimum thickness of reinforcing ring or saddle made from pipe (Use nominal thickness if made from plate.)
= 0, if there is no reinforcement pad or saddle

t = pressure design thickness of pipe, according to the appropriate wall thickness equation or procedure in 304.1. For welded pipe, when the branch does not intersect the longitudinal weld of the run, the basic allowable stress, S, for the pipe (see Appendix A, Note 16) may be used in determining t_h for the purpose of reinforcement calculation only. When the branch does intersect the longitudinal weld of the run, the allowable stress (SE) of the run pipe shall be used in the calculation. The allowable stress (SE) of the branch shall be used in calculating t_b.

β = smaller angle between axes of branch and run

(b) *Required Reinforcement Area.* The reinforcement area A_1 required for branch connections under internal pressure shall be:

$$A_1 = (t_h d_1)(2 - \sin\beta) \qquad (6a)$$

and under external pressure shall be:

$$A_1 = (t_h d_1)(2 - \sin\beta)/2 \qquad (6b)$$

(c) *Reinforcement Area:* The reinforcement area is the sum of Areas $A_2 + A_3 + A_4$ defined below, and shall equal or exceed the required reinforcement area, A_1, in 304.3.3(b).

(1) Area A_2. The area lying within the reinforcement zone resulting from any excess thickness available in the run wall:

$$A_2 = (2d_2 - d_1)(T_h - t_h - c) \qquad (7)$$

(2) Area A_3. The area lying within the reinforcement zone resulting from any excess thickness available in the branch pipe wall:

$$A_3 = 2L_4\,(T_b - t_b - c)/\sin\beta \qquad (8)$$

(3) Area A_4. The area of all other metal within the reinforcement zone defined in 304.3.3(d) provided by weld metal and other reinforcement metal properly attached to the run or branch. In computing areas of weld metal deposits, the minimum dimensions required in 327.4.4 shall be used unless the welder is clearly instructed to provide specific larger dimensions, in which case the latter dimensions may be used in calculations.

Materials used for reinforcement may differ from those of the run pipe, provided they are compatible with the run and branch pipes with respect to weldability, heat treating requirements, galvanic corrosion, thermal expansion, etc. If the allowable stress for such materials is less than that for the run pipe, the corresponding calculated area must be reduced in the ratio of the allowable stress values before being counted toward the reinforcement area. No additional credit shall be taken for materials having higher allowable stress values than the run pipe.

(d) *Reinforcement Zone.* The reinforcement zone is a parallelogram whose length extends a distance of d_2 on each side of the centerline of the branch pipe and whose width starts at the inside surface of the run pipe (in its corroded condition) and extends to a distance L_4 from the outside surface of the run pipe measured perpendicular to this outside surface.

(e) *Reinforcement of Multiple Openings.* When any two or more adjacent openings are so closely spaced that their reinforcement zones overlap

ASME/ANSI B31.3 PRESSURE REINFORCING PADS

Example 1

12.75	H OD	Header outside diameter (in)
0.375	HT	Header nominal wall thickness (in)
500.	HPSI	Header design pressure (psig)
20000.	SMAX	Header design stress (psi)
0.063	HCOR	Header corrosion allowance (in)
750.	HDEG	Header design temperature (°F)
1.	SMLS	Fabrication code (1 = seamless, 0 = plate)
8.625	B OD	Branch outside diameter (in)
0.322	BT	Branch nominal wall thickness (in)
500.	BPSI	Branch design pressure (psig)
20000.	SMAX	Branch design stress (psi)
0.063	BCOR	Branch corrosion allowance (in)
750.	BDEG	Branch design temperature (°F)
1.	SMLS	Fabrication code (1 = seamless, 0 = plate)
1.	MATL	Material code
90.	ANGL	Branch intersection angle (degrees)
0.265	HT'	Header milled and corroded wall (in)
0.219	BT'	Branch milled and corroded wall (in)
0.158	H-3A	Header minimum pressure thickness (in)
0.107	B-3A	Branch minimum pressure thickness (in)
8.188	D1	Length removed from pipe at branch (in)
8.188	D2	Half-width of reinforcement zone (in)
1.292	AR	Reinforcement area required (A1) (in^2)
0.547	L4	Height of reinforcement zone (in)
0.879	AH	Excess area in header wall (A2) (in^2)
0.123	AB	Excess area in branch wall (A3) (in^2)
1.001	AA	Area available for reinforcement (AH + AB)
0.125	THCK	Pad thickness (in)
1.163	WIDE	Pad width (in)

MATERIAL CODES:

1 = Ferritic Steel
2 = Austenitic Steel
3 = Other ductile materials
4 = Cast Iron

Pressure Pad Thickness

(Solution for Example 1)

H OD = 12.75″
HT = 0.375″
HT′ = (0.375)(7)/(8) − .063 = 0.2651″
B OD = 8.625″
BT = 0.322″
BT′ = (0.322)(7)/(8) − .063 = 0.2188″

$$H = 3A = \frac{(500)(12.75)}{2(20000 + (500)(0.4))} = 0.1578''$$

$$B = 3A = \frac{(500)(8.625)}{2(20000 + (500)(0.4))} = 0.1067''$$

$$D1 = \frac{8.625 - 2(0.2188)}{\text{SIN }(90)} = 8.1874''$$

$$D2 = \text{greater of } 8.1874 \quad \text{and} \quad (0.2651) + (0.2188) + \frac{8.1874}{2} = 4.5776''$$

L4 = lesser of 2.5(0.2651) = 0.6628″ and 2.5(0.2188) + 0 = <u>0.5740″</u>
AR = (0.1578)(8.1874)(2 − SIN(90)) = 1.2920

AH = (2(8.1874) − (8.1874))(0.2651 − 0.1578) = 0.8785

AB = 2(0.5470)(0.2188 − 0.1067)/SIN(90) = 0.1226

AA = 0.8785 + 0.1226 = 1.0011

AR′ = 1.2920 − 1.0011 = 0.2909

Assume pad thickness = 0.125″

Pad width = 0.2909/(2)/(0.125) = 1.1635″ ∴ less than D1

Example 2

12.75	H OD	Header outside diameter (in)
0.375	HT	Header nominal wall thickness (in)
500.	HPSI	Header design pressure (psig)
20000.	SMAX	Header design stress (psi)
0.063	HCOR	Header corrosion allowance (in)
950.	HDEG	Header design temperature (°F)
0.	SMLS	Fabrication code (1 = seamless, 0 = plate)
8.625	B OD	Branch outside diameter (in)
0.322	BT	Branch nominal wall thickness (in)
500.	BPSI	Branch design pressure (psig)
20000.	SMAX	Branch design stress (psi)
0.063	BCOR	Branch corrosion allowance (in)
925.	BDEG	Branch design temperature (°F)
0.	SMLS	Fabrication code (1 = seamless, 0 = plate)
1.	MATL	Material code
45.	ANGL	Branch intersection angle (degrees)
0.302	HT'	Header milled and corroded wall (in)
0.249	BT'	Branch milled and corroded wall (in)
0.157	H-3A	Header minimum pressure thickness (in)
0.107	B-3A	Branch minimum pressure thickness (in)
11.493	D1	Length removed from pipe at branch (in)
11.493	D2	Half-width of reinforcement zone (in)
2.339	AR	Reinforcement area required (A1) (in^2)
0.623	L4	Height of reinforcement zone (in)
1.662	AH	Excess area in header wall (A2) (in^2)
0.251	AB	Excess area in branch wall (A3) (in^2)
1.913	AA	Area available for reinforcement (AH + AB)
0.125	THCK	Pad thickness (in)
1.706	WIDE	Pad width (in)

MATERIAL CODES:

1 = Ferritic Steel
2 = Austenitic Steel
3 = Other ductile materials
4 = Cast Iron

Example 3

12.75	H OD	Header outside diameter (in)
0.688	HT	Header nominal wall thickness (in)
10.	HPSI	Header design pressure (psig)
20000.	SMAX	Header design stress (psi)
0.	HCOR	Header corrosion allowance (in)
120.	HDEG	Header design temperature (°F)
0.	SMLS	Fabrication code (1 = seamless, 0 = plate)
8.625	B OD	Branch outside diameter (in)
0.718	BT	Branch nominal wall thickness (in)
10.	BPSI	Branch design pressure (psig)
20000.	SMAX	Branch design stress (psi)
0.	BCOR	Branch corrosion allowance (in)
120.	BDEG	Branch design temperature (°F)
1.	SMLS	Fabrication code (1 = seamless, 0 = plate)
1.	MATL	Material code
90.	ANGL	Branch intersection angle (degrees)
0.678	HT'	Header milled and corroded wall (in)
0.628	BT'	Branch milled and corroded wall (in)
0.003	H-3A	Header minimum pressure thickness (in)
0.002	B-3A	Branch minimum pressure thickness (in)
7.369	D1	Length removed from pipe at branch (in)
7.369	D2	Half-width of reinforcement zone (in)
0.023	AR	Reinforcement area required (A1) (in^2)
1.571	L4	Height of reinforcement zone (in)
4.972	AH	Excess area in header wall (A2) (in^2)
1.967	AB	Excess area in branch wall (A3) (in^2)
6.939	AA	Area available for reinforcement (AH + AB)
	NO PAD	Pad thickness (in)
		Pad width (in)

MATERIAL CODES:
- 1 = Ferritic Steel
- 2 = Austenitic Steel
- 3 = Other ductile materials
- 4 = Cast Iron

Sample Problem

Program: TI-59-10

Header size is 12" std. wt.
Branch size is 8" sch 40.
Design pressure for both lines is 500 psig.
Maximum stress for both lines is 20,000 psi.
Corrosion allowance for both lines is 0.063".
Design temperature for both lines is 750°F.
Both lines are seamless pipe.
The material is ferritic steel.
The branch intersection angle is 90°.

Step	Input	Key Stroke	Display	Printer		Comments
1		E	0			Initialize program.
2	12.75	A	12.75	12.75	H OD	Input H OD, store in R01.
3	.375	A	0.375	0.375	HT	Input HT, store in R02.
4	500	A	500.	500.	HPSI	Input HPSI, store in R03.
5	20000	A	20000.	20000	SMAX	Input SMAX, store in R04.
6	.063	A	0.063	0.063	HCOR	Input HCOR, store in R05.
7	750	A	750.	750.	HDEG	Input HDEG, store in R06.
8	1	A	1.	1.	SMLS	Input SMLS, store in R07.
9	8.625	A	8.625	8.625	B OD	Input B OD, store in R08.
10	.322	A	0.322	0.322	BT	Input BT, store in R09.
11	500	A	500.	500.	BPSI	Input BPSI, store in R10.
12	20000	A	20000.	20000	SMAX	Input SMAX, store in R11.
13	0.63	A	0.063	0.063	BCOR	Input BCOR, store in R12.
14	750	A	750.	750.	BDEG	Input BDEG, store in R13.
15	1	A	1.	1.	SMLS	Input SMLS, store in R14.
16	1	A	1.	1.	MATL	Input MATL, store in R15.
17	90	A	90.	90.	ANGL	Input ANGL, store in R16.
18		B		0.265	HT'	The program calculates all of the
				0.219	BT'	data to determine if the branch
				0.158	H-3A	needs reinforcement: Wall thick-
				0.107	B-3A	nesses less corrosion allowances
				8.188	D1	and mill tolerances, minimum wall
				8.188	D2	thicknesses based on internal
				1.292	AR	pressure, reinforcement zone
				0.547	L4	dimensions, area required for rein-
				0.879	AH	forcement, excess area in header wall,
				0.123	AB	excess area in branch wall, and total
				1.001	AA	area available (AH + AB). If AA is
						greater than AR, the message "NO

Step	Input	Key Stroke	Display	Printer		Comments
				0.125 1.163	THCK WIDE	PAD" is printed. In this case, ther is not enough area and a pad is required. The program calculates t pad dimensions by assuming a wa thickness and solving for the widt If the pad width falls inside the rei forcing zone, the pad dimensions printed.

Coding Form

Program Number TI-59-10 **Title** Pressure Reinforcing Pads

Loc	Code	Key	Comments	Loc	Code	Key	Comments	Loc	Code	Key	Comments
000	98	ADV	Initialize program.	060	43	RCL		120	00	0	
001	02	2	Set pointers for	061	59	59		121	00	0	
002	09	9	input routine.	062	75	-		122	32	X⇌T	
003	42	STO		063	93	.		123	77	GE	
004	29	29		064	00	0		124	80	GRD	
005	25	CLR		065	01	1		125	75	-	
006	42	STO		066	95	=		126	32	X⇌T	
007	00	00		067	92	RTN		127	54	)	
008	91	R/S		068	76	LBL	Seamless pipe	128	65	×	
009	76	LBL		069	24	CE	tolerance is 12.5%.	129	93	.	
010	15	E		070	43	RCL		130	00	0	
011	81	RST		071	59	59		131	00	0	
012	76	LBL	Input routine.	072	65	×		132	04	4	
013	11	A	Uses R00 and R29	073	07	7		133	85	+	
014	32	X⇌T	for pointers.	074	55	÷		134	76	LBL	This section
015	69	OP		075	08	8		135	80	GRD	assigns Y = 0.7
016	20	20		076	95	=		136	93	.	for T > 1000°F.
017	01	1		077	92	RTN		137	07	7	
018	44	SUM		078	76	LBL	Subroutine:	138	95	=	
019	29	29		079	17	B'	Determines the	139	92	RTN	
020	73	RC*		080	42	STO	value of Y for the	140	76	LBL	Y = 0.4 for
021	29	29		081	59	59	pipe wall thickness	141	60	DEG	T ≤ 900°F.
022	69	OP		082	04	4	calculation. If	142	93	.	
023	04	04		083	32	X⇌T	temperature is less	143	04	4	
024	32	X⇌T		084	43	RCL	than 900°F Y = 0.4.	144	92	RTN	
025	69	OP		085	15	15		145	76	LBL	Y = 0.0 for cast
026	06	06		086	67	EQ		146	90	LST	iron.
027	72	ST*		087	90	LST		147	25	CLR	
028	00	00		088	43	RCL		148	92	RTN	
029	91	R/S		089	59	59		149	76	LBL	Main program.
030	76	LBL	Data printing	090	32	X⇌T		150	12	B	
031	19	D'	subroutine. Prints	091	08	8		151	02	2	
032	73	RC*	calculated values	092	09	9		152	32	X⇌T	
033	02	02	with alpha labels.	093	09	9		153	43	RCL	All temperatures
034	69	OP	Uses R01 and R02	094	77	GE		154	15	15	are normalized
035	04	04	as pointers and R00	095	60	DEG		155	67	EQ	to carbon steel
036	73	RC*	as a counter.	096	09	9	This section	156	59	INT	for purposes of
037	01	01		097	05	5	interpolates	157	77	GE	calculating Y.
038	58	FIX		098	00	0	between 900°F and	158	50	I×I	Stainless steel is
039	03	03		099	32	X⇌T	950°F (Y = 0.4 and	159	61	GTO	reduced by 150°F.
040	69	OP		100	77	GE	Y = 0.5). All	160	22	INV	Other ductile
041	06	06		101	70	RAD	temperatures are	161	76	LBL	materials are
042	69	OP		102	75	-	normalized to	162	59	INT	reduced by 600°F.
043	21	21		103	32	X⇌T	carbon steel.	163	01	1	
044	69	OP		104	54	)		164	05	5	
045	22	22		105	65	×		165	00	0	
046	22	INV		106	93	.		166	61	GTO	
047	58	FIX		107	00	0		167	57	ENG	
048	97	DSZ		108	00	0		168	76	LBL	
049	00	00		109	02	2		169	50	I×I	
050	19	D'		110	85	+		170	06	6	
051	92	RTN		111	93	.		171	00	0	
052	76	LBL	Subroutine:	112	05	5		172	00	0	
053	16	A'	Removes the mill	113	95	=		173	76	LBL	
054	29	CP	tolerance	114	92	RTN		174	57	ENG	
055	75	-	depending on the	115	76	LBL	This section	175	94	+/-	
056	01	1	value of SMLS.	116	70	RAD	interpolates	176	44	SUM	
057	95	=	Pipe fabricated	117	32	X⇌T	between 950°F and	177	06	06	
058	67	EQ	from plate has a	118	01	1	1000°F.	178	44	SUM	
059	24	CE	tolerance = .01".	119	00	0		179	13	13	

Loc	Code	Key	Comments	Loc	Code	Key	Comments	Loc	Code	Key	Comments
180	76	LBL	HT′ is calculated	240	54	)		300	19	19	
181	22	INV	and stored in R17.	241	65	×		301	65		
182	98	ADV		242	02	2		302	53		
183	43	RCL		243	55	÷		303	02	2	
184	02	02		244	43	RCL		304	75	−	
185	42	STO		245	10	10		305	43	RCL	
186	59	59		246	55	÷		306	16	16	
187	43	RCL		247	43	RCL		307	38	SIN	
188	07	07		248	08	08		308	95	=	
189	16	A′		249	95	=		309	42	STO	
190	75	−		250	35	1/X		310	23	23	
191	43	RCL		251	42	STO		311	02	2	L4 is calculated
192	05	05		252	20	20		312	93	.	and stored in R24.
193	95	=		253	43	RCL	D1 is calculated	313	05	5	Tr is assured to be
194	42	STO		254	08	08	and stored in R21.	314	65		zero.
195	17	17		255	75	−		315	43	RCL	
196	43	RCL	BT′ is calculated	256	02	2		316	17	17	
197	09	09	and stored in R18.	257	65	×		317	95	=	
198	42	STO		258	43	RCL		318	32	X⇌T	
199	59	59		259	18	18		319	02	2	
200	43	RCL		260	54	)		320	93	.	
201	14	14		261	55	÷		321	05	5	
202	16	A′		262	43	RCL		322	65	×	
203	75	−		263	16	16		323	43	RCL	
204	43	RCL		264	38	SIN		324	18	18	
205	12	12		265	95	=		325	95	=	
206	95	=		266	42	STO		326	22	INV	
207	42	STO		267	21	21		327	77	GE	
208	18	18		268	55	÷	D2 is calculated	328	25	CLR	
209	43	RCL	The minimum wall	269	02	2	and stored in R22.	329	32	X⇌T	
210	06	06	thickness for the	270	85	+	D2 must be less	330	76	LBL	
211	17	B′	header is calculated	271	43	RCL	than the header	331	25	CLR	
212	65	×	according to	272	17	17	OD.	332	42	STO	
213	43	RCL	equation 3A of	273	85	+		333	24	24	
214	03	03	ANSI B31.3, 1980.	274	43	RCL		334	65		AB is calculated
215	85	+	H-3A is stored in	275	18	18		335	02	2	and stored in R26.
216	43	RCL	R19.	276	95	=		336	65	×	
217	04	04		277	32	X⇌T		337	53		
218	54	)		278	43	RCL		338	43	RCL	
219	65	×		279	21	21		339	18	18	
220	02	2		280	77	GE		340	75	−	
221	55	÷		281	28	LOG		341	43	RCL	
222	43	RCL		282	32	X⇌T		342	20	20	
223	03	03		283	76	LBL		343	54		
224	55	÷		284	28	LOG		344	55	÷	
225	43	RCL		285	32	X⇌T		345	43	RCL	
226	01	01		286	43	RCL		346	16	16	
227	95	=		287	01	01		347	38	SIN	
228	35	1/X		288	22	INV		348	95	=	
229	42	STO		289	77	GE		349	42	STO	
230	19	19		290	29	CP		350	26	26	
231	43	RCL	The minimum wall	291	32	X⇌T		351	02	2	AH is calculated
232	13	13	thickness of the	292	76	LBL		352	65		and stored in R25.
233	17	B′	branch is calculated	293	29	CP		353	43	RCL	
234	65	×	according to	294	42	STO		354	22	22	
235	43	RCL	equation 3A of	295	22	22		355	75	−	
236	10	10	ANSI B31.3, 1980.	296	43	RCL	Area required	356	43	RCL	
237	85	+	B-3A is stored in	297	21	21	(AR) is calculated	357	21	21	
238	43	RCL	R20.	298	65	×	and stored in R23.	358	54	)	
239	11	11		299	43	RCL		359	65	×	

Loc	Code	Key	Comments
360	53	(	
361	43	RCL	
362	17	17	
363	75	-	
364	43	RCL	
365	19	19	
366	95	=	
367	42	STO	
368	25	25	
369	85	+	AA is calculated and stored in R27.
370	43	RCL	
371	26	26	
372	95	=	
373	42	STO	
374	27	27	
375	29	CP	AR-AA is stored in R59. If AA is negative, it is ignored.
376	77	GE	
377	23	LNX	
378	25	CLR	
379	76	LBL	
380	23	LNX	
381	94	+/-	
382	85	+	
383	43	RCL	
384	23	23	
385	95	=	
386	42	STO	
387	59	59	
388	08	8	Basic pad thickness (1/8″) is stored in R28.
389	35	1/X	
390	42	STO	
391	28	28	
392	02	2	2 D2 is stored in test register.
393	65	×	
394	43	RCL	
395	22	22	
396	95	=	
397	32	X⇌T	
398	76	LBL	Pad width is calculated. If the pad is larger than the allowed reinforcement area, 1/16″ is added to the thickness and the program tries again.
399	18	C'	
400	43	RCL	
401	59	59	
402	55	÷	
403	43	RCL	
404	28	28	
405	85	+	
406	43	RCL	
407	08	08	
408	95	=	
409	22	INV	
410	77	GE	
411	47	CMS	
412	01	1	
413	06	6	
414	35	1/X	
415	44	SUM	
416	28	28	
417	61	GTO	
418	18	C'	
419	76	LBL	

Loc	Code	Key	Comments
420	47	CMS	Pad width is stored in R29.
421	75	-	
422	43	RCL	
423	08	08	
424	54	)	
425	55	÷	
426	02	2	
427	95	=	
428	42	STO	
429	29	29	
430	01	1	All calculated data except pad dimensions is printed.
431	01	1	
432	42	STO	
433	00	00	
434	01	1	
435	07	7	
436	42	STO	
437	01	01	
438	04	4	
439	06	6	
440	42	STO	
441	02	02	
442	19	D'	
443	98	ADV	If no pad is required, go to TAN. If not, pad dimensions are printed.
444	43	RCL	
445	59	59	
446	29	CP	
447	22	INV	
448	77	GE	
449	30	TAN	
450	02	2	
451	42	STO	
452	00	00	
453	19	D'	
454	81	RST	
455	76	LBL	This section prints the message "NO PAD."
456	30	TAN	
457	03	3	
458	01	1	
459	69	OP	
460	03	03	
461	03	3	
462	02	2	
463	00	0	
464	00	0	
465	03	3	
466	03	3	
467	01	1	
468	03	3	
469	01	1	
470	06	6	
471	69	OP	
472	04	04	
473	69	OP	
474	05	05	
475	69	OP	
476	00	00	
477	81	RST	

Program HP-41CV-10: Pressure Reinforcing Pad Sizing

Introduction:

HP-41CV-10 performs calculations set out in ASME/ ANSI B31.3, 1980, to determine the need for and the dimensions of the reinforcing pad needed to contain internal pressure at a stub-in connection. The program prints out all the relevant data, such as reinforcing zone dimensions and required area to be replaced and the thickness and width of the required pad, or the message "NO PAD REQD" if there is sufficient area in the header and branch for pressure containment.

Nomenclature:

Fourteen pieces of data are needed to execute the program. The user must also answer a question regarding the method of manufacture for the header and the branch. The data are:

H OD:	Header outside diameter (in)
HT:	Header nominal or purchased wall thickness (in)
HPSI:	Header design pressure (psig)
HSMAX:	Header allowable stress (psi)
HCOR:	Header corrosion allowance (in)
HTEMP:	Header design temperature (°F)
B OD:	Branch outside diameter (in)
BT:	Branch nominal or purchased wall thickness (in)
BPSI:	Branch design pressure (psig)
BSMAX:	Branch allowable stress (psi)
BCOR:	Branch corrosion allowance (in)
BTEMP:	Branch design temperature (°F)
MATL:	Material code for the connection 1 = Ferritic steel 2 = Austenitic steel 3 = Other ductile materials 4 = Cast iron
ANGLE:	Angle of intersection of the branch and the header (Deg)

After prompting for the design temperature for both the header and the branch, the program displays the question "SEAMLESS?" If the header (or the branch) is fabricated as seamless pipe, the user must enter a Y. If the pipe is fabricated from plate, the user must enter an N. The program has already set the calculator in the alpha mode, so the user does not need to do Y is located at the "times" (×) key. N is located at the ENTER key.

The program calculates the following data:

HT':	Nominal wall thickness of the header less mill tolerance and corrosion allowance (in)
BT':	Same as above for the branch (in)
HTmin:	Minimum wall thickness of the header according to Equation 3A of ANSI B31.3, Section 304.1.2. (in)
BTmin:	Minimum wall thickness for the branch (in)
d1:	Effective length removed from pipe at branch (in)
d2:	"Half-width" of the reinforcement zone (in)
L4:	Height of reinforcement zone outside of run pipe (in)
Ar:	(A1) Reinforcement area required (in^2)
Ah:	(A2) Excess area in the header wall (in^2)
Ab:	(A3) Excess area in the branch wall (in^2)
Aa:	Area available for reinforcement (Ah + Ab) (in^2)

Method:

HP-41CV-10 performs the calculations set forth in ASME/ ANSI B31.3, 1980, Section 304.3.3. First, the corrosion allowance and the mill tolerance is removed from the input values of nominal header thickness and branch thickness. Mill tolerance for seamless pipe is 12½ percent. For pipe fabricated from plate, the mill tolerance is 0.01 in. The value to be used is decided by the user during input. Then the program calculates the minimum wall thickness needed to contain internal pressure, using Equation 3A in Section 304.1.2 of ANSI B31.3, 1980, for both the header and the branch. The value of Y used in the equation is determined by the program, using the input values of HTEMP and BTEMP. When necessary, Y is interpolated between the two values found in Section 304.1.2. Using these values and the other input data, the program determines the area needed for pressure containment, the area available in the branch and header walls, and the dimensions of the reinforcement zone. If the area available is greater than the area required, the program prints the message "NO PAD REQD." If the area available is insufficient, the program starts with a pad thickness of .125 in. and computes the pad width. If the width

falls within the reinforcement zone width, the program prints the reinforcing pad dimensions. If not, the pad thickness is increased by .0625 in and the process starts again.

There are two points the user should understand about the assumptions made by the program.

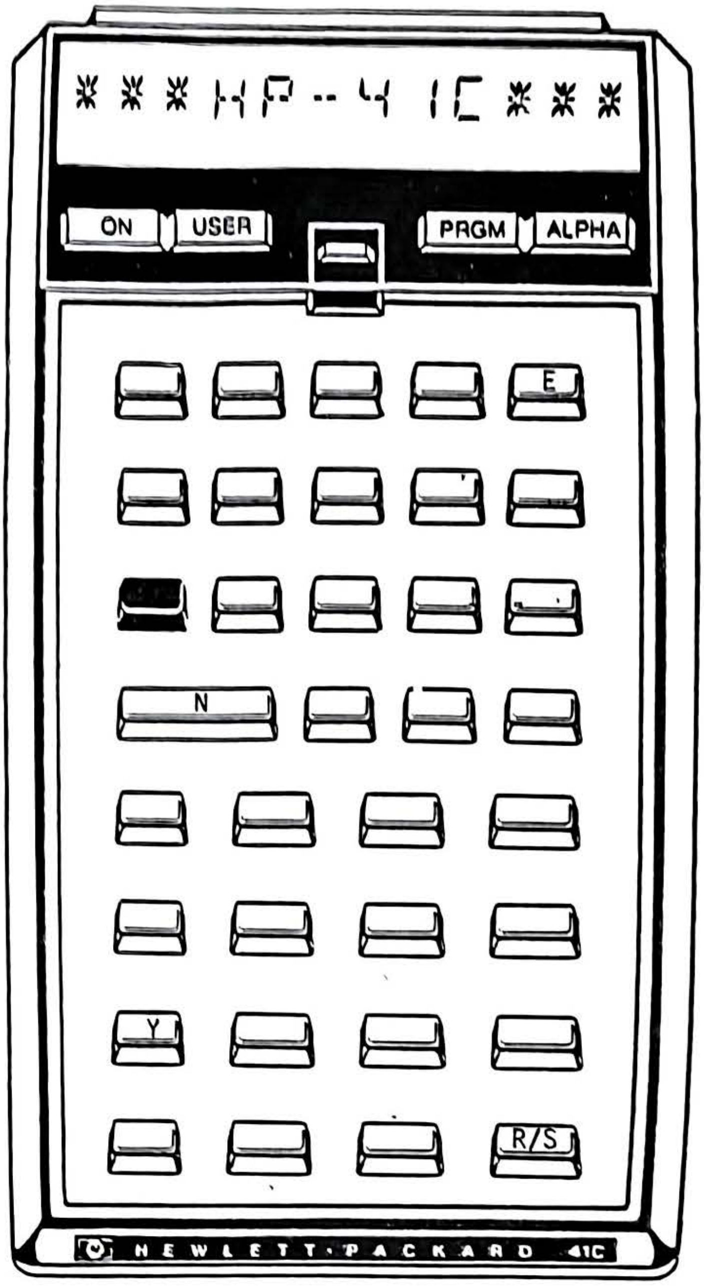
1. The program assumes no excess weld credit.
2. The program assumes that Tr is always zero, when calculating the value of L4.

Limitations:

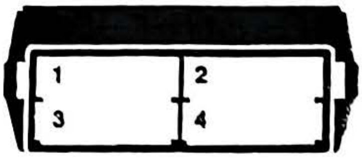
HP-41CV-10 performs one branch connection at a time. No data are carried over from one execution to another. The program is self-initializing. After the first run, the program initializes itself. The equations used are not applicable for pipes under external pressure. There is no check of the limits of the thickness the pad may be. There is also no way to calculate a branch connection made up of different materials.

Keyboard Card Labeling

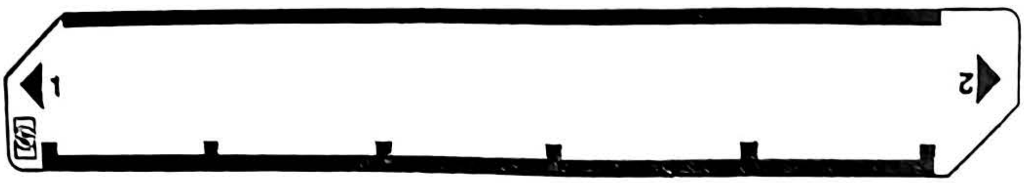
KEYBOARD



SYSTEM CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-10 **Title** Pressure Reinforcing Pad Sizing

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards (5).			
2	Initialize program.		E	H OD=
3	Input header outside diameter.	H OD	R/S	HT=
4	Input header thickness.	HT	R/S	HPSI=
5	Input header design pressure.	HPSI	R/S	HSMAX=
6	Input header allowable stress.	HSMAX	R/S	HCOR=
7	Input header corrosion allowance.	HCOR	R/S	HTEMP=
8	Input header design temperature.	HTEMP	R/S	SEAMLESS?
9	Answer seamless prompt.	Y or N	R/S	B OD=
10	Input branch outside diameter.	B OD	R/S	BT=
11	Input branch thickness.	BT	R/S	BPSI=
12	Input branch design pressure.	BPSI	R/S	BSMAX=
13	Input branch allowable stress.	BSMAX	R/S	BCOR=
14	Input branch corrosion allowance.	BCOR	R/S	BTEMP=
15	Input branch design temperature.	BTEMP	R/S	SEAMLESS?
16	Answer seamless prompt.	Y or N	R/S	1=FERRITIC 2=STAINLESS 3=0.DUCTILE 4=CAST IRON MATL=
17	Input material code.	1, 2, 3, or 4	R/S	ANGLE=
18	Input header/branch intersection angle.	ANGLE	R/S	HT ' BT ' HTmin BTmin d1 d2 L4 Ar Ah Ab Aa Thick Wide

Registers, Flags, Assignments

Program Number HP-41CV-10 **Title** Pressure Reinforcing Pads

DATA REGISTERS

00	Pointer
01	H OD
02	HT
03	HPSI
04	HSMAX
05	HCOR
06	HTEMP
07	B OD
08	BT
09	BPSI
10	BSMAX
11	BCOR
12	BTEMP
13	MATL
14	ANGLE
15	HT'
16	BT'
17	HTmin
18	BTmin
19	d1
20	d2
21	L4
22	Ar
23	Ah
24	Ab
25	Aa
26	THICK
27	WIDE
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	
38	

DATA REGISTERS

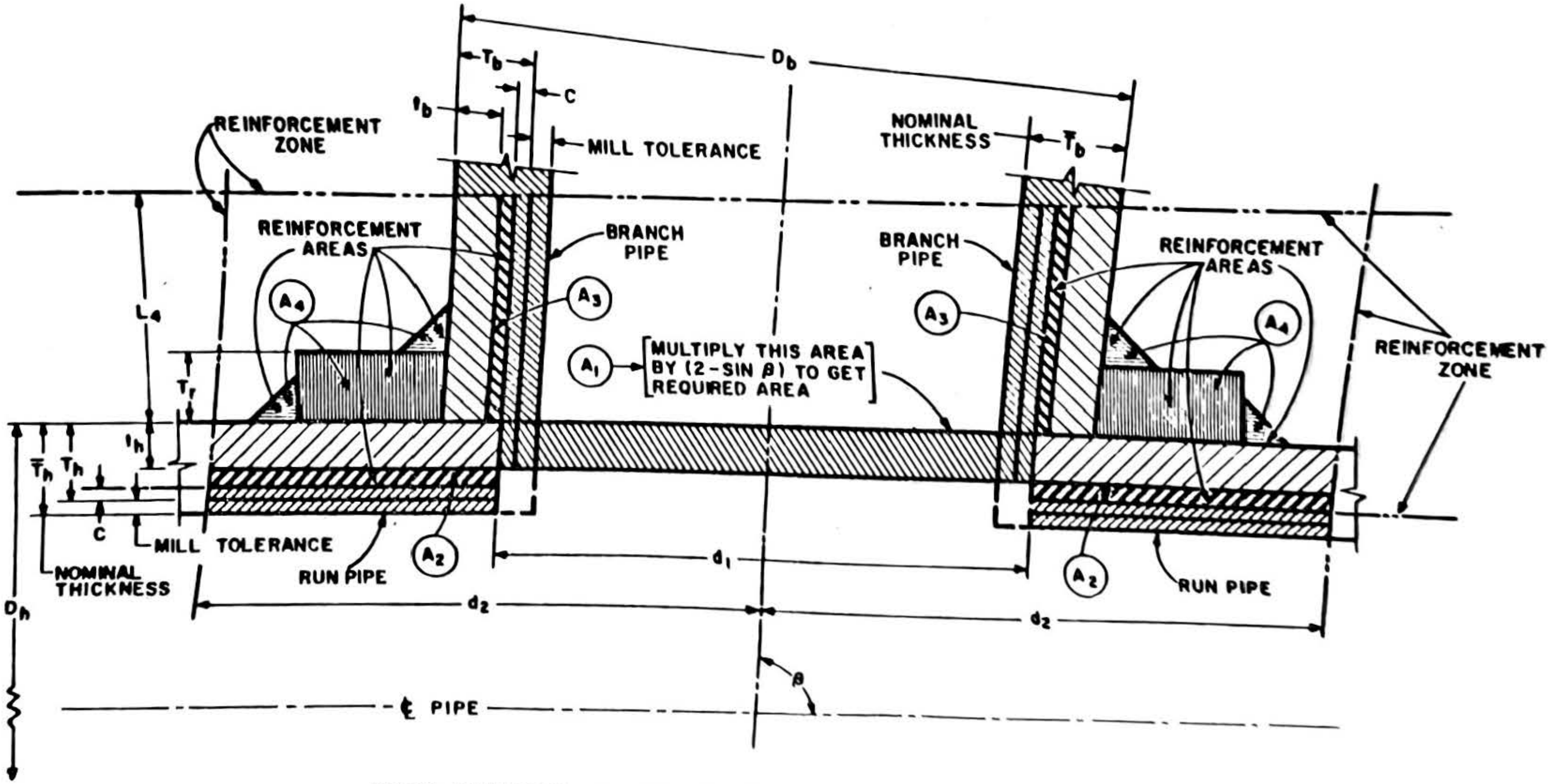
39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates
1	C	Header is plate fabricated.	Header is Seamless
2	C	Branch is plate fabricated	Branch is Seamless

ASSIGNMENTS

Label	Key	Function	Key
PAD	15 (E)		



NOTE: THIS FIGURE ILLUSTRATES THE NOMENCLATURE OF 304.3.3. IT DOES NOT INDICATE COMPLETE WELDING DETAILS OR A PREFERRED METHOD OF CONSTRUCTION. FOR TYPICAL WELD DETAILS, SEE FIGURE 327.4.4D.

(a)

FIG. 304.3.3 BRANCH CONNECTION NOMENCLATURE

304.3.3 Reinforcement of Welded Branch Connections. Added reinforcement is required to meet the criteria in 304.3.3(b) and (c) when it is not provided inherently in the components of the branch connection. Sample problems illustrating the calculations for branch reinforcement are shown in Appendix H.

(a) *Nomenclature.* The nomenclature below is used in the pressure design of branch connections. It is illustrated in Fig. 304.3.3, which does not indicate details for construction or welding. Some of the terms defined in Appendix J are subject to further definitions or variations, as follows:

b = subscript referring to branch

d_1 = effective length removed from pipe at branch

d_2 = "half width" of reinforcement zone
= d_1 or $(T_b - c) + (T_h - c) + d_1/2$, whichever is greater, but in any case not more than D_h

h = subscript referring to run or header

L_4 = height of reinforcement zone outside of run pipe
= $2.5(T_h - c)$ or $2.5(T_b - c) + T_r$, whichever is less

T_r = minimum thickness of reinforcing ring or saddle made from pipe (Use nominal thickness if made from plate.)
= 0, if there is no reinforcement pad or saddle

t = pressure design thickness of pipe, according to the appropriate wall thickness equation or procedure in 304.1. For welded pipe, when the branch does not intersect the longitudinal weld of the run, the basic allowable stress, S, for the pipe (see Appendix A, Note 16) may be used in determining t_h for the purpose of reinforcement calculation only. When the branch does intersect the longitudinal weld of the run, the allowable stress (SE) of the run pipe shall be used in the calculation. The allowable stress (SE) of the branch shall be used in calculating t_b.

β = smaller angle between axes of branch and run

(b) *Required Reinforcement Area.* The reinforcement area A_1 required for branch connections under internal pressure shall be:

$$A_1 = (t_h d_1)(2 - \sin\beta) \tag{6a}$$

and under external pressure shall be:

$$A_1 = (t_h d_1)(2 - \sin\beta)/2 \tag{6b}$$

(c) *Reinforcement Area:* The reinforcement area is the sum of Areas $A_2 + A_3 + A_4$ defined below, and shall equal or exceed the required reinforcement area, A_1, in 304.3.3(b).

(1) Area A_2. The area lying within the reinforcement zone resulting from any excess thickness available in the run wall:

$$A_2 = (2d_2 - d_1)(T_h - t_h - c) \tag{7}$$

(2) Area A_3. The area lying within the reinforcement zone resulting from any excess thickness available in the branch pipe wall:

$$A_3 = 2L_4(T_b - t_b - c)/\sin\beta \tag{8}$$

(3) Area A_4. The area of all other metal within the reinforcement zone defined in 304.3.3(d) provided by weld metal and other reinforcement metal properly attached to the run or branch. In computing areas of weld metal deposits, the minimum dimensions required in 327.4.4 shall be used unless the welder is clearly instructed to provide specific larger dimensions, in which case the latter dimensions may be used in calculations.

Materials used for reinforcement may differ from those of the run pipe, provided they are compatible with the run and branch pipes with respect to weldability, heat treating requirements, galvanic corrosion, thermal expansion, etc. If the allowable stress for such materials is less than that for the run pipe, the corresponding calculated area must be reduced in the ratio of the allowable stress values before being counted toward the reinforcement area. No additional credit shall be taken for materials having higher allowable stress values than the run pipe.

(d) *Reinforcement Zone.* The reinforcement zone is a parallelogram whose length extends a distance of d_2 on each side of the centerline of the branch pipe and whose width starts at the inside surface of the run pipe (in its corroded condition) and extends to a distance L_4 from the outside surface of the run pipe measured perpendicular to this outside surface.

(e) *Reinforcement of Multiple Openings.* When any two or more adjacent openings are so closely spaced that their reinforcement zones overlap

Example 1

```
H OD= 12.750
HT= 0.375
HPSI= 500.000
HSMAX= 20,000.000
HCOR= 0.063
HTEMP= 750.000
SEAMLESS? Y

B OD= 8.625
BT= 0.322
BPSI= 500.000
BSMAX= 20,000.000
BCOR= 0.063
BTEMP= 750.000
SEAMLESS? Y

MATL= 1.
ANGLE= 90.

HT'=0.265
BT'=0.219
HTmin=0.158
BTmin=0.107

                d1=8.188
                d2=8.189
                L4=0.547
                Ar=1.292
                Ah=0.879
                Ab=0.123
                Aa=1.001

        PAD
    DIMENSIONS

             0.125 in THICK
             1.163 in WIDE
```

Header size is 12″ std. wt.
Branch size is 8″ sch 40.
Design pressure for both lines is 500 psig.
Maximum stress for both lines is 20,000 psi.
Corrosion allowance for both lines is 0.063″.
Design temperature for both lines is 750°F.
Both lines are seamless pipe.
The material is #1 (ferritic steel).
The branch intersection angle is 90°.

Pressure Pad Thickness

(Solution for Example 1)

H OD = 12.75″
HT = 0.375″
HT′ = (0.375)(7)/(8) − .063 = 0.2651″
B OD = 8.625″
BT = 0.322″
BT′ = (0.322)(7)/(8) − .063 = 0.2188″

$$\text{HTmin} = \text{3A} \quad \text{Minimum required wall for header} = \frac{(500)(12.75)}{2(20000 + (500)(0.4))} = 0.1578''$$

$$\text{BTmin} = \text{3A} \quad \text{Minimum required wall for branch} = \frac{(500)(8.625)}{2(20000 + (500)(0.4))} = 0.1067''$$

$$\text{D1} = \frac{8.625 - 2(0.2188)}{\text{SIN }(90)} = 8.1874''$$

$$\text{D2} = \text{greater of } 8.1874 \quad \text{and} \quad (0.2651) + (0.2188) + \frac{8.1874}{2} = 4.5776''$$

L4 = lesser of 2.5(0.2651) = 0.6628″ and 2.5(0.2188) + 0 = 0.5740″
Ar = (0.1578)(8.1874)(2 − SIN(90)) = 1.2920

Ah = (2(8.1874) − (8.1874))(0.2651 − 0.1578) = 0.8785

Ab = 2(0.5470)(0.2188 − 0.1067)/SIN(90) = 0.1226

Aa = 0.8785 + 0.1226 = 1.0011

AR′ = 1.2920 − 1.0011 = 0.2909

Assume pad thickness = 0.125″

Pad width = 0.2909/(2)/(0.125) = 1.1635″ ∴ less than D1

Example 2

```
H OD= 12.750
HT= 0.375
HPSI= 500.000
HSMAX= 20,000.000
HCOR= 0.063
HTEMP= 950.000
SEAMLESS? N

B OD= 8.625
BT= 0.322
BPSI= 500.000
BSMAX= 20,000.000
BCOR= 0.063
BTEMP= 925.000
SEAMLESS? N

MATL= 1.
ANGLE= 45.

HT'=0.302
BT'=0.249
HTmin=0.157
BTmin=0.107

                d1=11.493
                d2=11.493
                 L4=0.623
                 Ar=2.339
                 Ah=1.662
                 Ab=0.251
                 Aa=1.913

        PAD
     DIMENSIONS

             0.125 in THICK
              1.706 in WIDE
```

The header size is 12″ std. wt.
The branch size is 8″ sch 40.
The design pressure for both lines is 500 psig.
The allowable stress for both lines is 20,000 psi.
The corrosion allowance for both lines is 0.063″.
Design temperature for the header is 950°F.
Design temperature for the branch is 925°F.
Both lines are fabricated from plate.
The material is #1 (ferritic steel).
The branch intersection angle is 45°.

Example 3

H OD= 12.750	The header size is 12″ sch 80.
HT= 0.688	The header design pressure is 10 psig.
HPSI= 10.000	The header allowable stress is 20,000 psi.
HSMAX= 20,000.000	The header corrosion allowance is 0″.
HCOR= 0.000	Design temperature for the header is 120°F.
HTEMP= 120.000	The header is fabricated from plate.
SEAMLESS? N	
B OD= 8.625	The branch size is 8″ sch 120.
BT= 0.718	The branch design pressure is 10 psig.
BPSI= 10.000	The branch allowable stress is 20,000 psi.
BSMAX= 20,000.000	The branch corrosion allowance is 0″.
BCOR= 0.000	Design temperature for the branch is 120°F.
BTEMP= 120.000	The branch is seamless pipe.
SEAMLESS? Y	
MATL= 1.	The material is #1 (ferritic steel).
ANGLE= 90.	The branch intersection angle is 90°.

```
HT'=0.678
BT'=0.628
HTmin=0.003
BTmin=0.002

                d1=7.369
                d2=7.369
                L4=1.571
                Ar=0.023
                Ah=4.972
                Ab=1.967
                Aa=6.939

NO PAD REQD
```

Sample Problem

Program: HP-41CV-10 Title Pressure Reinforcing Pads

Sample Problem (Sketch if Desired)

Header size is 12" std. wt.
Branch size is 8" sch 40.
Design pressure for both lines is 500 psig.
Maximum stress for both lines is 20,000 psi.
Corrosion allowance for both lines is 0.063".
Design temperature for both lines is 750° F.
Both lines are seamless pipe.
The material is ferritic steel.
The branch intersection angle is 90° F.

Input	Function	Display	Comments
	E	H OD=	Initialize program.
12.75	R/S	HT=	Store H OD, prompt for HT.
.375	R/S	HPSI=	Store HT, prompt for HPSI.
500	R/S	HSMAX=	Store HPSI, prompt for HSMAX.
20000	R/S	HCOR=	Store HSMAX, prompt for HCOR.
.063	R/S	HTEMP=	Store HCOR, prompt for HTEMP.
750	R/S	SEAMLESS?	Store HTEMP, ask if header is seamless pipe.
Y	R/S	B OD=	Program does *not* set Flag 1 because header is seamless. Prompt for B OD.
8.625	R/S	BT=	Store B OD, prompt for BT.
.322	R/S	BPSI=	Store BT, prompt for BPSI.
500	R/S	BSMAX=	Store BPSI, prompt for BSMAX.
20000	R/S	BCOR=	Store BSMAX, prompt for BCOR.
.063	R/S	BTEMP=	Store BCOR, prompt for BTEMP.
750	R/S	SEAMLESS?	Store BTEMP, ask if branch is seamless pipe.
Y	R/S	1=FERRETIC 2=STAINLESS 3=0.DUCTILE 4=CAST IRON MATL=	Program does not set Flag 2 because branch is seamless. Display material codes and prompt MATL.
1	R/S	ANGLE=	Store MATL, prompt for ANGLE.

Input	Function	Display	Comments
90	R/S	HT'=0.265 BT'=0.219 HTmin=0.158 BTmin=0.107	Program calculates and prints corroded and milled wall thickness for header and branch, and minium wall thickness based on internal pressure for branch and header.
		d1=8.188 d2=8.188 L4=0.547 Ar=1.292 Ah=0.879 Ab=0.123 Aa=1.001 PAD DIMENSIONS 0.125 in THICK 1.163 in WIDE	The program then calculates and prints the data to determine the amount of reinforcing needed: reinforcement zone dimensions, area needed for reinforcement, excess area in the header and branch, and area available (Ah + Ab). If Aa is grater than Ar, the program prints the message "NO PAD REQD." If, as in this case, additional reinforcement is needed, the program assumes a pad thickness and calculates a pad width. If the pad dimensions fall within the reinforcement zone, the pad thickness and width are printed.

Coding Form

Program Number HP-41CV-10 **Title** Pressure Reinforcing Pads

Step/Line Key Entry	Key Code	Comments
01♦LBL "PAD"		Initialize program. Clears all registers, clears Flags 1 and 2, stores all alpha labels for input routine.
02 CLRG		
03 CF 01		
04 CF 02		
05 "H OD"		
06 ASTO 01		
07 "HT"		
08 ASTO 02		
09 "HPSI"		
10 ASTO 03		
11 "HSMAX"		
12 ASTO 04		
13 "HCOR"		
14 ASTO 05		
15 "HTEMP"		
16 ASTO 06		
17 "B OD"		
18 ASTO 07		
19 "BT"		
20 ASTO 08		
21 "BPSI"		
22 ASTO 09		
23 "BSMAX"		
24 ASTO 10		
25 "BCOR"		
26 ASTO 11		
27 "BTEMP"		
28 ASTO 12		
29 FIX 3		
30 1.006		
31 STO 00		
32♦LBL A		Input routine. Uses R00 as pointer and counter. Prompts for and stores all header data.
33 CLA		
34 SF 12		
35 ARCL IND 00		
36 "⊢="		
37 PROMPT		
38 ACA		
39 CF 12		
40 ACX		
41 PRBUF		
42 STO IND 00		
43 ISG 00		
44 GTO A		
45 "Y"		Prompts for "SEAMLESS?" or not. If header is made from plate (user input = N), program sets Flag 1.
46 ASTO Y		
47 "SEAMLESS? "		
48 SF 12		
49 ACA		
50 AON		
51 PROMPT		
52 CF 12		
53 ACA		
54 ASTO X		
55 AOFF		
56 PRBUF		
57 X=Y?		
58 GTO 10		
59 SF 01		
60♦LBL 10		Input routine. Uses R00 as pointer and counter. Prompts for and stores all branch data.
61 7.012		
62 STO 00		
63 ADV		
64♦LBL B		
65 CLA		
66 SF 12		
67 ARCL IND 00		
68 "⊢="		
69 PROMPT		
70 ACA		
71 CF 12		
72 ACX		
73 PRBUF		
74 STO IND 00		
75 ISG 00		
76 GTO B		
77 "Y"		Prompts for "SEAMLESS?" or not. If branch is made from plate (user input = N) program sets Flag 2.
78 ASTO Y		
79 "SEAMLESS? "		
80 SF 12		
81 ACA		
82 AON		
83 PROMPT		
84 CF 12		
85 ACA		
86 ASTO X		
87 AOFF		
88 PRBUF		
89 X=Y?		
90 GTO 15		
91 SF 02		
92♦LBL 15		Program displays the codes for the four different material classes.
93 ADV		
94 AON		
95 "1=FERRETIC"		
96 PSE		
97 "2=STAINLESS"		
98 PSE		
99 "3=0, DUCTILE"		
100 PSE		
101 "4=CAST IRON"		
102 PSE		
103 AOFF		
104 SF 12		Prompts for, prints, and stores MATL in R13. Prompts for, prints, and stores ANGLE in R14.
105 "MATL="		
106 PROMPT		
107 ACA		
108 STO 13		
109 CF 12		
110 FIX 0		
111 ACX		
112 PRBUF		
113 "ANGLE="		
114 SF 12		
115 PROMPT		
116 ACA		
117 STO 14		
118 CF 12		
119 ACX		
120 PRBUF		
121 ADV		This section removes the mill tolerance and corrosion allowance from HT to get HT'. The result is stored in R15.
122 RCL 02		
123 FS? 01		
124 GTO 20		
125 7		
126 *		
127 8		
128 /		
129 GTO 21		
130♦LBL 20		
131 .01		
132 -		
133♦LBL 21		
134 RCL 05		
135 -		
136 STO 15		
137 RCL 08		This section removes the mill tolerance and corrosion allowance from BT to get BT'. The result is stored in R16.
138 FS? 02		
139 GTO 25		
140 7		
141 *		
142 8		
143 /		
144 GTO 26		

Step/ Line	Key Entry	Key Code	Comments
145	♦LBL 25		
146	.01		
147	-		
148	♦LBL 26		
149	RCL 11		
150	-		
151	STO 16		
152	2		The temperature of all materials is normalized to carbon steel for purposes of calculating the Y factor. Stainless is reduced by 150°F, other ductile materials by 600°F.
153	RCL 13		
154	X<Y?		
155	GTO C		
156	X=Y?		
157	GTO D		
158	4		
159	X=Y?		
160	GTO C		
161	600		
162	GTO 30		
163	♦LBL D		
164	150		
165	♦LBL 30		
166	ST- 06		
167	ST- 12		
168	♦LBL C		HTmin is calculated according to equation 3A of ANSI B31.3 1980.
169	RCL 06		
170	XEQ "Y"		
171	RCL 03		
172	*		
173	RCL 04		
174	+		
175	2		
176	*		
177	1/X		HTmin is stored in R17.
178	RCL 01		
179	*		
180	RCL 03		
181	*		
182	STO 17		
183	RCL 12		BTmin is calculated according to Equation 3A of ANSI B31.3, 1980. BT min is stored in R18.
184	XEQ "Y"		
185	RCL 09		
186	*		
187	RCL 10		
188	+		
189	2		
190	*		
191	1/X		
192	RCL 07		
193	*		

Step/ Line	Key Entry	Key Code	Comments
194	RCL 09		
195	*		
196	STO 18		
197	ADV		HT', BT', HTmin, and BTmin are printed.
198	FIX 3		
199	"HT"		
200	ACA		
201	39		
202	ACCHR		
203	"="		
204	ARCL 15		
205	ACA		
206	PRBUF		
207	"BT"		
208	ACA		
209	39		
210	ACCHR		
211	"="		
212	ARCL 16		
213	ACA		
214	PRBUF		
215	"HT"		
216	ACA		
217	SF 13		
218	"MIN="		
219	ARCL 17		
220	ACA		
221	PRBUF		
222	CF 13		
223	"BT"		
224	ACA		
225	SF 13		
226	"MIN="		
227	ARCL 18		
228	ACA		
229	PRBUF		
230	CF 13		d1 is calculated and stored in R19.
231	ADV		
232	RCL 07		
233	RCL 16		
234	2		
235	*		
236	-		
237	RCL 14		
238	SIN		
239	/		
240	STO 19		
241	2		d2 is calculated and stored in R20. d2
242	/		

Step/ Line	Key Entry	Key Code	Comments
243	RCL 15		must be less than the header OD.
244	RCL 16		
245	+		
246	+		
247	RCL 19		
248	X>Y?		
249	GTO 17		
250	X<>Y		
251	♦LBL 17		
252	RCL 01		
253	X<=Y?		
254	GTO 18		
255	X<>Y		
256	♦LBL 18		
257	STO 20		
258	RCL 15		L4 is calculated and stored in R21. Tr is assumed to be zero.
259	2.5		
260	*		
261	RCL 16		
262	2.5		
263	*		
264	X<=Y?		
265	GTO 31		
266	X<>Y		
267	♦LBL 31		
268	STO 21		
269	RCL 17		Ar is calculated and stored in R22.
270	RCL 19		
271	*		
272	2		
273	RCL 14		
274	SIN		
275	-		
276	*		
277	STO 22		
278	RCL 20		Ah is calculated and stored in R23.
279	2		
280	*		
281	RCL 19		
282	-		
283	RCL 15		
284	RCL 17		
285	-		
286	*		
287	STO 23		
288	2		Ab is calculated and stored in R24.
289	RCL 21		
290	*		
291	RCL 16		

Step/Line	Key Entry	Key Code	Comments
292	RCL 18		
293	-		
294	*		
295	RCL 14		
296	SIN		
297	/		
298	STO 24		
299	RCL 23		Aa is calculated and stored in R25.
300	+		
301	STO 25		
302	RCL 22		Ar-Aa is stored in R26.
303	X<>Y		
304	-		
305	STO 26		
306	FIX 3		d1, d2, L4, Ar, Ah, Ab, and Aa are printed.
307	"d1="		
308	ARCL 19		
309	ACA		
310	ADV		
311	"d2="		
312	ARCL 20		
313	ACA		
314	ADV		
315	"L4="		
316	ARCL 21		
317	ACA		
318	ADV		
319	"A"		
320	ACA		
321	SF 13		
322	"R="		
323	ARCL 22		
324	ACA		
325	ADV		
326	CF 13		
327	"A"		
328	ACA		
329	SF 13		
330	"H="		
331	ARCL 23		
332	ACA		
333	ADV		
334	CF 13		
335	"Ab="		
336	ARCL 24		
337	ACA		
338	ADV		
339	"Aa="		
340	ARCL 25		

Step/Line	Key Entry	Key Code	Comments
341	ACA		
342	ADV		
343	ADV		If Aa is greater than Ar, no pad is required. The program prints "NO PAD REQ'D" and resets.
344	RCL 25		
345	RCL 22		
346	X>Y?		
347	GTO 50		
348	SF 12		
349	"NO PAD REQD"		
350	PRA		
351	ADV		
352	ADV		
353	CF 12		
354	GTO "PAD"		
355	♦LBL 50		If a pad is required, 1/8" is stored in R26 as the smallest pad thickness. If Aa is less than zero, then it is ignored and Ar is the basis of the pad size.
356	.125		
357	STO 26		
358	♦LBL E		
359	RCL 22		
360	RCL 25		
361	X>0?		
362	GTO F		
363	CLX		
364	♦LBL F		
365	-		
366	RCL 26		
367	/		
368	RCL 07		
369	+		If the pad size is larger than the reinforcing zone, then 1/16" is added to the pad thickness and the program tries again.
370	RCL 20		
371	2		
372	*		
373	X>Y?		
374	GTO 51		
375	.0625		
376	ST+ 26		
377	GTO E		
378	♦LBL 51		Pad width is stored in R27.
379	X<>Y		
380	2		
381	/		
382	RCL 07		
383	2		
384	/		
385	-		
386	STO 27		
387	SF 12		Pad thickness and width are printed
388	FMT		
389	"PAD"		

Step/Line	Key Entry	Key Code	Comments
390	ACA		and the program resets.
391	PRBUF		
392	FMT		
393	"DIMENSIONS"		
394	ACA		
395	PRBUF		
396	ADV		
397	CF 12		
398	CLA		
399	ARCL 26		
400	ACA		
401	SF 13		
402	" IN "		
403	ACA		
404	CF 13		
405	"THICK"		
406	ACA		
407	ADV		
408	CLA		
409	ARCL 27		
410	ACA		
411	SF 13		
412	" IN "		
413	ACA		
414	CF 13		
415	"WIDE"		
416	ACA		
417	ADV		
418	ADV		
419	ADV		
420	GTO "PAD"		
421	♦LBL "Y"		Subroutine: Determines the value of Y for the minimum pipe wall thickness calculations. If $T < 900$°F, $Y = 0.4$. Y is interpolated between 0.4 and 0.5 for $900 \leq T \leq 950$.
422	RCL 13		
423	4		
424	X=Y?		
425	GTO 01		
426	RDN		
427	RDN		
428	899		
429	X>Y?		
430	GTO 04		
431	RDN		
432	950		
433	X<Y?		
434	GTO 05		
435	X<>Y		
436	-		
437	.002		
438	CHS		

Step/ Line	Key Entry	Key Code	Comments	Step/ Line	Key Entry	Key Code	Comments	Step/ Line	Key Entry	Key Code	Comments
439	*										
440	.5										
441	+										
442	RTN										
443	♦LBL 05		Y is interpolated between 0.5 and 0.7 for 950 ≤ T ≤ 1000. All temperatures are normalized to carbon steel. For T < 900°F Y = 0.4 For cast iron, Y = 0.0.								
444	RDN										
445	1000										
446	X<Y?										
447	GTO 07										
448	X<>Y										
449	-										
450	-.004										
451	*										
452	.7										
453	+										
454	RTN										
455	♦LBL 01										
456	0										
457	RTN										
458	♦LBL 04										
459	.4										
460	RTN										
461	♦LBL 07										
462	.7										
463	RTN										
464	.END.										

Chapter 11

Maximum Allowable Working Pressure

Program TI-59-11.1

Introduction:

Given a pipe outside diameter, nominal wall thickness, allowable stress and corrosion allowance, TI-59-11.1 will return a maximum pressure that can be sustained by the pipe, according to ASME/ANSI B31.3, 1980.

Nomenclature:

Six pieces of data are input:

OD:	Pipe outside diameter (in)
THCK:	Pipe wall thickness (nominal) (in)
SMAX:	Hot stress allowable (psi)
TEMP:	Design temperature (°F)
CORR:	Corrosion allowance plus thread allowance, if any (in)
MATL:	Material code

The material codes are:

1 = Ferritic steel
2 = Austenitic steel
3 = Other ductile materials
4 = Cast iron

User keys are:

A:	Input data
B:	Execute for seamless pipe
C:	Execute for plate-fabricated pipe
E:	Initialize program

Method:

The equation used is based on Equation 3a of ASME/ANSI B31.3, 1980, Section 304.1.2.

$$PMAX = \frac{SMAX(2T')}{OD} \times \frac{1}{1 - (2YT'/OD)}$$

where

$T' = 7/8(THCK) - CORR$ for seamless pipe
$T' = THCK - CORR - 0.01$ for plate-fabricated pipe
Y = temperature factor (from Table 304.1.1, ASME/ANSI B31.3, 1980)

Limitations:

TI-59-11.1 operates on one OD at a time. It does not check against the use of cast iron above 900°F. Only English units may be used.

User Instructions

Program Number TI-59-11.1 **Title** Maximum Allowances Working Pressure

Step	Instructions	Input	Keystroke	Display
1	Initialize.		E	0
2	Input OD (in).	OD	A	OD
3	Input THCK (in).	THCK	A	THCK
4	Input SMAX (psi).	SMAX	A	SMAX
5	Input TEMP (°F).	TEMP	A	TEMP
6	Input CORR (in).	CORR	A	CORR
7	Input MATL (1, 2, 3, or 4).	MATL	A	MATL
8	Select analysis.			
	SEAMLESS		B	PMAX
	PLATE		C	PMAX

TI-59-11.1 initializes itself after every run.

Data Register Contents

REGISTER	DATA	REGISTER	DATA
00	DSZ	30	
01	OD	31	
02	THCK	32	
03	SMAX	33	
04	TEMP	34	
05	CORR	35	
06	MATL	36	
07	Y factor	37	
08	Corroded and milled thickness (t')	38	
09	Normalized temperature	39	
10	PMAX	40	
11		41	
12		42	
13		43	
14		44	
15		45	
16		46	
17		47	
18		48	
19		49	
20		50	
21		51	
22		52	
23		53	
24		54	
25		55	
26		56	
27		57	
28		58	
29		59	

Examples of TI-59-11.1

8.625	OD
0.1819	THCK
20000.	SMAX
900.	TEMP
0.063	CORR
1.	MATL

SEAMLESS

450.	PMAX

8.625	OD
0.169	THCK
20000.	SMAX
1100.	TEMP
0.063	CORR
2.	MATL

PLATE

450.	PMAX

8.625	OD
0.1819	THCK
20000.	SMAX
1156.	TEMP
0.063	CORR
3.	MATL

SEAMLESS

450.	PMAX

8.625	OD
0.17	THCK
20000.	SMAX
954.	TEMP
0.063	CORR
4.	MATL

PLATE

450.	PMAX

Sample Problem

Program: TI-59-11.1

OD = 8.625"
THCK = 0.1819"
SMAX = 20,000 psi
TEMP = 900°F
CORR = 0.063"
MATL = Ferritic steel (Code = 1)

Step	Input	Key Stroke	Display	Printer		Comments
1		E	0.			Initialize program.
2	8.625	A	8.625	8.625	OD	Stores OD in R01.
3	.1819	A	0.1819	0.1819	THCK	Stores THCK in R02.
4	20000	A	20000.	20000.	SMAX	Stores SMAX in R03.
5	900	A	900.	900.	TEMP	Stores TEMP in R04.
6	.063	A	0.063	0.063	CORR	Stores CORR in R05.
7	1	A	1.	1.	MATL	Stores MATL in R06.
8		B		SEAMLESS 450.	 PMAX	The program executes the equations for seamless pipe. The value of Y is calculated and stored in R07. The mill tolerance (12 1/2% for this case) is taken from the nominal thickness, THCK. The corrosion allowance is also taken off. The value of t' is stored in R08. Using t', PMAX is calculated and stored in R10. The value is then printed.

Coding Form

Program Number TI-59-11.1 **Title** Maximum Allowable Working Pressure

Loc	Code	Key	Comments
000	76	LBL	Input routine. Uses R00 as a pointer.
001	11	A	
002	32	X:T	
003	73	RC*	
004	00	00	
005	69	OP	
006	04	04	
007	32	X:T	
008	69	OP	
009	06	06	
010	72	ST*	
011	00	00	
012	69	OP	
013	20	20	
014	69	OP	
015	00	00	
016	91	R/S	
017	76	LBL	Main control for seamless pipe. Loads alpha registers with "SEAMLESS?"
018	12	B	
019	03	3	
020	06	6	
021	01	1	
022	07	7	
023	01	1	
024	03	3	
025	69	OP	
026	02	02	
027	03	3	
028	00	0	
029	02	2	
030	07	7	
031	01	1	
032	07	7	
033	03	3	
034	06	6	
035	03	3	
036	06	6	
037	69	OP	
038	03	03	
039	61	GTO	
040	33	X²	
041	76	LBL	Main control for plate-fabricated pipe. Loads alpha registers with "PLATE."
042	13	C	
043	25	CLR	
044	69	OP	
045	02	02	
046	03	3	
047	03	3	
048	02	2	
049	07	7	
050	01	1	
051	03	3	
052	03	3	
053	07	7	
054	01	1	
055	07	7	Sets PLATE flag.
056	69	OP	
057	03	03	
058	86	STF	
059	03	03	

Loc	Code	Key	Comments
060	76	LBL	Prints alpha label.
061	33	X²	
062	98	ADV	
063	69	OP	
064	05	05	
065	69	OP	
066	00	00	
067	98	ADV	
068	03	3	Test to see if material is #3 or #4.
069	32	X:T	
070	43	RCL	
071	06	06	
072	67	EQ	
073	25	CLR	
074	77	GE	
075	29	CP	
076	86	STF	Set Flag 1 if material is #1 or Flag 2 if material is 2. Normalize temperature to stainless steel, if necessary.
077	40	IND	
078	06	06	
079	22	INV	
080	87	IFF	
081	01	01	
082	24	CE	
083	01	1	
084	05	5	
085	00	0	
086	85	+	
087	76	LBL	
088	24	CE	
089	43	RCL	
090	04	04	
091	95	=	
092	42	STO	
093	09	09	
094	01	1	First test to assign value to Y. This section determines if Y = 0.4 or if Y = 0.7.
095	00	0	
096	04	4	
097	09	9	
098	32	X:T	
099	43	RCL	
100	09	09	
101	22	INV	
102	77	GE	
103	25	CLR	
104	01	1	
105	01	1	
106	05	5	
107	01	1	
108	32	X:T	
109	43	RCL	
110	09	09	
111	77	GE	
112	23	LNX	
113	01	1	Test to see if temperature is greater than 1100°F (normalized).
114	01	1	
115	00	0	
116	00	0	
117	32	X:T	
118	43	RCL	
119	09	09	

Loc	Code	Key	Comments
120	77	GE	
121	30	TAN	
122	01	1	Interpolation routine between 1050°F and 1100°F (normalized) interpolates Y between 0.4 and 0.5.
123	01	1	
124	00	0	
125	00	0	
126	75	-	
127	43	RCL	
128	09	09	
129	54	)	
130	65	×	
131	93	.	
132	00	0	
133	00	0	
134	02	2	
135	94	+/-	
136	85	+	
137	93	.	
138	05	5	
139	95	=	
140	42	STO	
141	07	07	
142	61	GTO	
143	38	SIN	
144	76	LBL	Interpolation routine between 1100°F and 1150°F (normalized) interpolates Y between 0.5 and 0.7.
145	30	TAN	
146	01	1	
147	01	1	
148	05	5	
149	00	0	
150	75	-	
151	43	RCL	
152	09	09	
153	54	)	
154	65	×	
155	93	.	
156	00	0	
157	00	0	
158	04	4	
159	94	+/-	
160	85	+	
161	76	LBL	If temperature > 1150°F 0.7 is the assigned value of Y.
162	23	LNX	
163	93	.	
164	07	7	
165	95	=	
166	42	STO	
167	07	07	
168	61	GTO	
169	38	SIN	
170	76	LBL	If temperature < 1050°F 0.4 is the assigned value of Y.
171	25	CLR	
172	93	.	
173	04	4	
174	42	STO	
175	07	07	
176	61	GTO	
177	38	SIN	
178	76	LBL	If MATL is cast iron Y = 0.00.
179	29	CP	

Loc	Code	Key	Comments
180	00	0	
181	42	STO	
182	07	07	
183	76	LBL	Calculates out mill tolerance.
184	38	SIN	
185	87	IFF	
186	03	03	
187	34	√X	
188	43	RCL	
189	02	02	
190	65	×	
191	07	7	
192	55	÷	
193	08	8	
194	95	=	
195	61	GTO	
196	35	1/X	
197	76	LBL	
198	34	√X	
199	43	RCL	
200	02	02	
201	75	-	
202	93	.	
203	00	0	
204	01	1	
205	95	=	
206	76	LBL	Calculates PMAX.
207	35	1/X	
208	75	-	
209	43	RCL	
210	05	05	
211	95	=	
212	42	STO	
213	08	08	
214	65	×	
215	02	2	
216	65	×	
217	43	RCL	
218	03	03	
219	55	÷	
220	43	RCL	
221	01	01	
222	95	=	
223	42	STO	
224	09	09	
225	01	1	
226	75	-	
227	53	(	
228	43	RCL	
229	07	07	
230	65	×	
231	02	2	
232	65	×	
233	43	RCL	
234	08	08	
235	55	÷	
236	43	RCL	
237	01	01	
238	54	)	
239	95	=	

Loc	Code	Key	Comments
240	55	÷	
241	43	RCL	
242	09	09	
243	95	=	
244	35	1/X	
245	95	=	
246	42	STO	Stores PMAX in R10.
247	10	10	
248	03	3	Prints value of PMAX.
249	03	3	
250	03	3	
251	00	0	
252	01	1	
253	03	3	
254	04	4	
255	04	4	
256	69	OP	
257	04	04	
258	43	RCL	
259	10	10	
260	58	FIX	
261	00	00	
262	69	OP	
263	06	06	
264	22	INV	
265	58	FIX	
266	98	ADV	
267	76	LBL	
268	15	E	
269	22	INV	
270	86	STF	Initializing routine.
271	01	01	
272	22	INV	
273	86	STF	
274	02	02	Reset flags.
275	22	INV	
276	86	STF	
277	03	03	Clear test register.
278	29	CP	
279	47	CMS	
280	03	3	
281	02	2	Clear memories.
282	01	1	
283	06	6	
284	42	STO	
285	01	01	Set alpha labels.
286	03	3	
287	07	7	
288	02	2	
289	03	3	
290	01	1	
291	05	5	
292	02	2	
293	06	6	
294	42	STO	
295	02	02	
296	03	3	
297	06	6	
298	03	3	
299	00	0	

Loc	Code	Key	Comments
300	01	1	
301	03	3	
302	04	4	
303	04	4	
304	42	STO	
305	03	03	
306	03	3	
307	07	7	
308	01	1	
309	07	7	
310	03	3	
311	00	0	
312	03	3	
313	03	3	
314	42	STO	
315	04	04	
316	01	1	
317	05	5	
318	03	3	
319	02	2	
320	03	3	
321	05	5	
322	03	3	
323	05	5	
324	42	STO	
325	05	05	
326	03	3	
327	00	0	
328	01	1	
329	03	3	
330	03	3	
331	07	7	
332	02	2	
333	07	7	
334	42	STO	
335	06	06	
336	01	1	
337	42	STO	
338	00	00	Set pointer for input routine.
339	25	CLR	
340	91	R/S	

Program TI-59-11.2: Minimum Pipe Wall Thickness Per Individual OD

Introduction:

TI-59-11.2 performs the opposite calculation of TI-59-11.1. It determines the minimum pipe wall thickness when given the internal pressure, allowable stress, corrosion allowance, and type of material. The program differentiates between seamless pipe and pipe fabricated from plate. The equations used conform with ASME/ANSI B31.3, 1980.

Nomenclature:

Six pieces of data are input:

- OD: Pipe outside diameter (in)
- PRES: Internal pressure (psig)
- SMAX: Hot allowable stress (psi)
- TEMP: Design temperature (°F)
- CORR: Corrosion allowance plus thread allowance, if any (in)
- MATL: Material code

The material codes are:

1 = Ferritic steel
2 = Austenitic steel
3 = Other ductile materials
4 = Cast iron

User keys are:

- A: Input data
- B: Execute for seamless pipe
- C: Execute for plate-fabricated pipe
- E: Initialize program

Method:

The equations used are found in Section 304.1.2 of ASME/ANSI B31.3, 1980, Equation 3a. Mill tolerance for seamless pipe is 12.5 percent and 0.01 in for plate.

Limitations:

TI-59-11.2 deals with only one OD at a time. A flag is printed if the pipe wall thickness is greater that OD/6. The program does not check agains the use of cast iron above 900°F. Only English units may be used.

User Instructions

Program Number TI-59-11.2 **Title** Minimum Pipe Wall Thickness

Step	Instructions	Input	Keystroke	Display
1	Initialize program.		E	0
2	Input OD (in).	OD	A	OD
3	Input PRES (psig).	PRES	A	PRES
4	Input SMAX (psi)	SMAX	A	SMAX
5	Input TEMP (°F)	TEMP	A	TEMP
6	Input CORR (in).	CORR	A	CORR
7	Input MATL (1, 2, 3, or 4).	MATL	A	MATL
8	Select Analysis.			
	SEAMLESS		B	T
	PLATE		C	T

TI-59-11.2 initializes itself after every run.

Data Register Contents

REGISTER	DATA	REGISTER	DATA
00	Pointer	30	
01	OD	31	
02	PRESS	32	
03	SMAX	33	
04	TEMP	34	
05	CORR	35	
06	MATL	36	
07	Y factor	37	
08	T minimum	38	
09	adjusted temperature	39	
10	T	40	
11		41	
12		42	
13		43	
14		44	
15		45	
16		46	
17		47	
18		48	
19		49	
20		50	
21		51	
22		52	
23		53	
24		54	
25		55	
26		56	
27		57	
28		58	
29		59	

```
  8.625        OD
   450.      PRES
 20000.      SMAX
   900.      TEMP
  0.063      CORR
     1.      MATL
 SEAMLESS

0.1819          T
```

```
  8.625        OD
   450.      PRES
 20000.      SMAX
  1100.      TEMP
  0.063      CORR
     2.      MATL
    PLATE

0.1690          T
```

```
  8.625        OD
   450.      PRES
 20000.      SMAX
  1156.      TEMP
  0.063      CORR
     3.      MATL
 SEAMLESS

0.1819          T
```

```
  8.625        OD
   450.      PRES
 20000.      SMAX
   954.      TEMP
  0.063      CORR
     4.      MATL
    PLATE

0.1700          T
```

```
      8.625        OD
      4500.      PRES
      2000.      SMAX
      1750.      TEMP
      0.125      CORR
         4.      MATL
     SEAMLESS

    11.2321         T
=OD/6
```

Excessive OD/T Ratio Flag

Sample Problem

Program: TI-59-11.2

OD = 8.625"
PRES = 450 psig
SMAX = 20,000 psi
TEMP = 900°F
CORR = 0.063"
MATL = Ferritic steel (Code =1)

Step	Input	Key Stroke	Display	Printer	Comments
1		E	0.		Initialize program.
2	8.625	A	8.625	8.625 OD	Stores OD in R01.
3	450	A	450	450. PRES	Stores PRES in R02.
4	20000	A	20000.	20000. SMAX	Stores SMAX in R03.
5	900	A	900.	900. TEMP	Stores TEMP in R04.
6	0.063	A	0.063	0.063 CORR	Stores CORR in R05.
7	1	A	1.	1. MATL	Stores MATl in R06.
8		B	0.	SEAMLESS 0.1819 T	The program executes all the equations for seamiess pipe. The value of Y is calculated and stored in R07. The minimum thickness from Equation 3a is calculated. The corro-sion allowance is added and the mill tolerance (12 1/2% in this case) is also added. The final value of T is stored in R10. The value is com-pared with OD/6. The T value is printed.

Coding Form

Program Number TI-59-11.2 Title Minimum Pipe Wall Thickness

Loc	Code	Key	Comments
	76	LBL	Input routine; uses R00 as a pointer.
	11	A	
	32	X⇄T	
	73	RC*	
	00	00	
	69	OP	
	04	04	
	32	X⇄T	
	69	OP	
	06	06	
010	72	ST*	
011	00	00	
012	69	OP	
013	20	20	
014	69	OP	
015	00	00	
016	91	R/S	
017	76	LBL	Subroutine: Calculates minimum wall thickness per equation 3a.
018	16	A'	
019	43	RCL	
020	01	01	
021	65	×	
022	43	RCL	
023	02	02	
024	55	÷	
025	02	2	
026	55	÷	
027	53	(	
028	43	RCL	
029	03	03	
030	85	+	
031	43	RCL	
032	02	02	
033	65	×	
034	43	RCL	
035	07	07	
036	54	)	
037	85	+	
038	43	RCL	
039	05	05	
040	95	=	
041	42	STO	
042	08	08	
043	92	RTN	
044	76	LBL	Main control for seamless pipe. Loads alpha registers with "SEAMLESS."
045	12	B	
046	03	3	
047	06	6	
048	01	1	
049	07	7	
050	01	1	
051	03	3	
052	69	OP	
053	02	02	
054	03	3	
055	00	0	
056	02	2	
057	07	7	
058	01	1	
059	07	7	

Loc	Code	Key	Comments
060	03	3	
061	06	6	
062	03	3	
063	06	6	
064	69	OP	
065	03	03	
066	61	GTO	
067	00	00	
068	88	88	
069	76	LBL	Main control for plate-fabricated pipe. Loads alpha registers with "PLATE."
070	13	C	
071	25	CLR	
072	69	OP	
073	02	02	
074	03	3	
075	03	3	
076	02	2	
077	07	7	
078	01	1	
079	03	3	
080	03	3	
081	07	7	
082	01	1	
083	07	7	
084	69	OP	
085	03	03	Sets "PLATE" flag.
086	86	STF	
087	03	03	
088	69	OP	Print alpha label.
089	05	05	
090	69	OP	
091	00	00	
092	98	ADV	
093	03	3	Test to see if material is #3 or #4.
094	32	X⇄T	
095	43	RCL	
096	06	06	
097	67	EQ	
098	25	CLR	
099	77	GE	
100	29	CP	
101	86	STF	Set Flag 1 if material is #1, or Flag 2 if material is #2.
102	40	IND	
103	06	06	
104	22	INV	
105	87	IFF	
106	01	01	
107	24	CE	
108	01	1	
109	05	5	
110	00	0	
111	85	+	Normalize temperature to stainless steel, if necessary.
112	76	LBL	
113	24	CE	
114	43	RCL	
115	04	04	
116	95	=	
117	42	STO	
118	09	09	
119	01	1	

Loc	Code	Key	Comments
120	00	0	First test to assign value of Y. This section determines if Y = 0.4 or if Y = 0.7.
121	04	4	
122	09	9	
123	32	X⇄T	
124	43	RCL	
125	09	09	
126	22	INV	
127	77	GE	
128	25	CLR	
129	01	1	
130	01	1	
131	05	5	
132	01	1	
133	32	X⇄T	
134	43	RCL	
135	09	09	
136	77	GE	
137	23	LNX	
138	01	1	Test to see if temperature is greater than 1100°F (normalized).
139	01	1	
140	00	0	
141	00	0	
142	32	X⇄T	
143	43	RCL	
144	09	09	
145	77	GE	
146	30	TAN	
147	01	1	Interpolation routine between 1050°F and 1100°F (normalized). Interpolates Y between 0.4 and 0.5.
148	01	1	
149	00	0	
150	00	0	
151	75	−	
152	43	RCL	
153	09	09	
154	54	)	
155	65	×	
156	93	.	
157	00	0	
158	00	0	
159	02	2	
160	94	+/−	
161	85	+	
162	93	.	
163	05	5	
164	95	=	
165	42	STO	
166	07	07	
167	61	GTO	
168	38	SIN	
169	76	LBL	Interpolation routine between 1100°F and 1150°F (normalized) interpolates Y between 0.5 and 0.7.
170	30	TAN	
171	01	1	
172	01	1	
173	05	5	
174	00	0	
175	75	−	
176	43	RCL	
177	09	09	
178	54	)	
179	65	×	

Loc	Code	Key	Comments
180	93	.	
181	00	0	
182	00	0	
183	04	4	
184	94	+/-	
185	85	+	
186	76	LBL	
187	23	LNX	If temperature > 1150 0.7 is the assigned value of Y.
188	93	.	
189	07	7	
190	95	=	
191	42	STO	
192	07	07	
193	61	GTO	
194	38	SIN	
195	76	LBL	If temperature < 1050 0.4 is the assigned value of Y.
196	25	CLR	
197	93	.	
198	04	4	
199	42	STO	
200	07	07	
201	61	GTO	
202	38	SIN	
203	76	LBL	If MATL is cast iron, Y = 0.0.
204	29	CP	
205	00	0	
206	42	STO	
207	07	07	
208	76	LBL	Calculates Tmin and adds mill tolerance.
209	38	SIN	
210	16	A'	
211	87	IFF	
212	03	03	
213	34	ΓX	
214	43	RCL	
215	08	08	
216	65	×	
217	08	8	
218	55	÷	
219	07	7	
220	95	=	
221	42	STO	
222	10	10	
223	61	GTO	
224	35	1/X	Stores Tmin in R10.
225	76	LBL	
226	34	ΓX	
227	43	RCL	
228	08	08	
229	85	+	
230	93	.	
231	00	0	
232	01	1	
233	95	=	
234	76	LBL	
235	35	1/X	
236	42	STO	
237	10	10	
238	32	X:T	Test if Tmin ⩾ OD/6.
239	69	OP	

Loc	Code	Key	Comments
240	00	00	
241	43	RCL	
242	01	01	
243	55	÷	
244	06	6	
245	95	=	
246	77	GE	
247	70	RAD	
248	06	6	Load alpha register with "=OD/6."
249	04	4	
250	03	3	
251	02	2	
252	01	1	
253	06	6	
254	06	6	
255	03	3	
256	00	0	
257	07	7	
258	69	OP	
259	01	01	
260	76	LBL	
261	70	RAD	
262	03	3	
263	07	7	
264	69	OP	
265	04	04	
266	43	RCL	
267	10	10	
268	58	FIX	
269	04	04	
270	69	OP	Prints Tmin.
271	06	06	
272	25	CLR	
273	22	INV	
274	58	FIX	
275	69	OP	Prints flag, if any.
276	04	04	
277	69	OP	
278	05	05	
279	25	CLR	
280	76	LBL	Initialize.
281	15	E	
282	22	INV	
283	86	STF	Reset all flags.
284	01	01	
285	22	INV	
286	86	STF	Clear test register.
287	02	02	
288	22	INV	
289	86	STF	
290	03	03	Clear all memories.
291	29	CP	
292	47	CMS	
293	03	3	Set alpha labels.
294	02	2	
295	01	1	
296	06	6	
297	42	STO	
298	01	01	
299	03	3	

Loc	Code	Key	Comments
300	03	3	
301	03	3	
302	05	5	
303	01	1	
304	07	7	
305	03	3	
306	06	6	
307	42	STO	
308	02	02	
309	03	3	
310	06	6	
311	03	3	
312	00	0	
313	01	1	
314	03	3	
315	04	4	
316	04	4	
317	42	STO	
318	03	03	
319	03	3	
320	07	7	
321	01	1	
322	07	7	
323	03	3	
324	00	0	
325	03	3	
326	03	3	
327	42	STO	
328	04	04	
329	01	1	
330	05	5	
331	03	3	
332	02	2	
333	03	3	
334	05	5	
335	03	3	
336	05	5	
337	42	STO	
338	05	05	
339	03	3	
340	00	0	
341	01	1	
342	03	3	
343	03	3	
344	07	7	
345	02	2	
346	07	7	
347	42	STO	
348	06	06	
349	01	1	
350	42	STO	
351	00	00	
352	25	CLR	Set pointer for input routine.
353	91	R/S	

Program TI-59-11.3: Pipe Thickness, Class Array, for Seamless Pipe and Pipe Fabricated from Plate

Introduction:

TI-59-11.3 is an extension of TI-59-11.2. Whereas the latter provides the user with a pipe thickness for a specific pipe size, this program provides the pipe thickness for all pipe sizes, from 1/2 in to 36 in for seamless pipe, and from 16 in to 36 in for pipe fabricated from plate, in a given class. The user inputs the temperature, pressure, allowable stress, and corrosion allowance, and the program provides all the pipe sizes and their respective wall thicknesses. TI-59-11.3 does not check for high temperature when cast iron is noted, nor does it check to see if the wall thickness is one-sixth of the pipe diameter. The program deals with carbon steel, stainless steel, cast iron, and what the code terms "other ductile materials."

Nomenclature:

The user provides the program with six pieces of data:

- THRD: Threaded or not threaded class; 1 = yes, 0 = no
- PSI: Internal pressure (psig)
- SMAX: Allowable stress (psi)
- DEG: Maximum temperature (°F)
- MATL: Material code
  - 1 = Ferritic steel
  - 2 = Austenitic steel
  - 3 = Other ductile materials
  - 4 = Cast iron
- CORR: Corrosion allowance (in)

Three user-keys operate the program:

- A: Input of data
- B: Execute for seamless pipe
- C: Execute for pipe fabricated from plate
- E: Initialize

Method:

The equation used is Equation 3a found in ANSI/ASME B31.3, 1980. Mill tolerance for seamless pipe is 12½ percent; .01 in for pipe fabricated from plate. Thread allowance is .060 in for 1/2 in and 3/4 in, .075 in for 1 in through 2 in. Thread allowance is not added to stainless steel in the 2-in size.

Limitations:

TI-59-11.3 is set to provide a certain array of pipe sizes. For the seamless array, those sizes *not* included are: 1¼ in, 2½ in, 3½ in, 5 in, 22 in, 26 in, and sizes above 36 in. For pipe fabricated from plate, the array includes all sizes from 16 in to 36 in, excluding 34 in. The program makes no check against temperature or pipe thickness limitations as defined in ANSI/ASME B31.3, 1980. The program uses only English units. The program is self-initializing after the first run; that is, after the initial analysis, the user does not have to repeat Step 2 of the user instructions.

User Instructions

Program Number TI-59-11.3 **Title** Pipe Thickness for Seamless Pipe

Step	Instructions	Input	Keystroke	Display
1	Read magnetic cards (3 sides).		CLR	1, 2, and 3
2	Initialize program.		E	0
3	Input thread code.	THRD	A	THRD
4	Input internal pressure.	PSI	A	PSI
5	Input allowable stress.	SMAX	A	SMAX
6	Input temperature.	DEG	A	DEG
7	Input material code.	MATL	A	MATL
8	Input corrosion allowance.	CORR	A	CORR
9	Execute seamless analysis.		B	array

User Instructions

Program Number TI-59-11.3 **Title** Pipe Thickness for Pipe from Plate

Step	Instructions	Input	Keystroke	Display
1	Read magnetic cards (3 sides).		CLR	1, 2, and 3
2	Initialize program.		E	0
3	Input thread code.	0 (zero)	A	0
4	Input internal pressure.	PSI	A	PSI
5	Input allowable stress.	SMAX	A	SMAX
6	Input temperature.	DEG	A	DEG
7	Input material code.	MATL	A	MATL
8	Input corrosion allowance.	CORR	A	CORR
9	Execute pipe from plate analysis.		C	array

Data Register Contents

REGISTER	DATA	REGISTER	DATA
00	DSZ	30	36302736
01	THRD	31	3327133717
02	PRES	32	.84
03	SMAX	33	1.05
04	DEG	34	1.315
05	MATL	35	1.9
06	CORR	36	2.375
07		37	3.5
08	IND	38	4.5
09	DSZ	39	6.625
10		40	8.625
11		41	10.75
12	Thread allowance	42	12.75
13		43	14
14	Y factor	44	16
15		45	18
16		46	20
17		47	22
18		48	24
19		49	26
20		50	28
21		51	30
22		52	36
23		53	37233516
24		54	333624
25		55	36301344
26		56	161722
27		57	30133727
28		58	15323535
29		59	

Example 1

INTERNAL PRESSURE PIPEWALL CALCULATIONS

SEAMLESS — **PLATE**

1.	THRD	*Threaded class
450.	PSI	Internal pressure
20000.	SMAX	Allowable stress
650.	DEG	Temperature
1.	MATL	Material Code
0.063	CORR	Corrosion allowance.

SMLS — Seamless schedule — Plate schedule

Size	Thickness		Seamless schedule	Plate schedule
0.5	0.1513	T	160	
0.75	0.1540	T	80	
1.	0.1745	T	80	
1.5	0.1819	T	80	
2.	0.1880	T	80	
3.	0.1166	T	40	
4.	0.1293	T	40	
6.	0.1564	T	40	
8.	0.1819	T	20	
10.	0.2090	T	20	
12.	0.2345	T	20	
14.	0.2504	T	20	
16.	0.2759	T	20	
18.	0.3014	T	20	
20.	0.3268	T	20	
24.	0.3778	T	30	
30.	0.4543	T	20	
36.	0.5307	T	30	

*1 = threaded; 0 = not threaded
Internal pressure = psig
Allowable stress = psi
Temperature = °F
Material code:
- 1 = Ferritic
- 2 = Austenitic
- 3 = Other ductile material
- 4 = Cast iron

Corrosion allowance = inches

Example 2

INTERNAL PRESSURE PIPEWALL CALCULATIONS

SEAMLESS | **PLATE**

Input	Value	Code
*Threaded class	0.	THRD
Internal pressure	450.	PSI
Allowable stress	15000.	SMAX
Temperature	950.	DEG
Material Code	1.	MATL
Corrosion allowance.	0.125	CORR

PLATE

Seamless schedule	Plate printout		Plate schedule
	16.		
	0.3715	-	STD
	18.		
	0.4010	-	30
	20.		
	0.4306	-	30
	22.		
	0.4601	-	XS
	24.		
	0.4897	-	XS
	26.		
	0.5192	-	SPECIAL
	28.		
	0.5488	T	SPECIAL
	30.		
	0.5783	-	30
	32.		
	0.6079	T	SPECIAL
	36.		
	0.6670	T	40

*1 = threaded; 0 = not threaded
Internal pressure = psig
Allowable stress = psi
Temperature = °F
Material code:
- 1 = Ferritic
- 2 = Austenitic
- 3 = Other ductile material
- 4 = Cast iron

Corrosion allowance = inches

PART 2: PRESSURE DESIGN OF PIPING COMPONENTS

303 GENERAL

Components manufactured in accordance with standards listed in Table 326.1 and Table A326.1 shall be considered suitable for use at pressure-temperature ratings in accordance with 302.2 or A302.2. The rules in 304 and A304 usually are for the pressure design of components not covered in 302.2 or A302.2, but may be used for a special or more rigorous design of components covered by 302.2 or A302.2. Designs shall be checked for adequacy of mechanical strength under applicable loadings enumerated in 301.

304 PRESSURE DESIGN OF METALLIC COMPONENTS

(For nonmetallic components see A304.)

304.1 Straight Metallic Pipe

304.1.1 General

(a) The required thickness of straight sections of pipe shall be determined in accordance with Equation 2:

$$t_m = t + c \tag{2}$$

The minimum thickness for the pipe selected, considering manufacturer's minus tolerance, shall not be less than t_m.

(b) The following nomenclature is used in the equations for pressure design of straight pipe.

t_m = minimum required thickness, including mechanical, corrosion, and erosion allowances

t = pressure design thickness, as calculated in 304.1.2 for internal pressure, or in accordance with the procedure listed in 304.1.3 for external pressure

c = the sum of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowances. For threaded components, the nominal thread depth (dimension h of ANSI B2.1, or equivalent) shall apply. For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.02 in. (0.5 mm) in addition to the specified depth of the cut.

d = inside diameter of pipe. For design calculations, the inside diameter of the pipe is the maximum value allowable under purchase specifications.

P = internal design gage pressure

D = outside diameter of pipe

SE = allowable stress, from Appendix A

S = basic allowable stress for materials, excluding casting, joint or structural grade quality factors

E = quality factor as defined in 302.3.1(a)

Table 304.1.1
Values of Coefficient, Y, when t is Less Than $D/6$

Materials	900 (485) & Lower	950 (510)	1,000 (540)	1,050 (560)	1,100 (595)	1,150 (620) & up
	Temperature, °F (°C)					
Ferritic Steels	0.4	0.5	0.7	0.7	0.7	0.7
Austenitic Steels	0.4	0.4	0.4	0.4	0.5	0.7
Other ductile Metals	0.4	0.4	0.4	0.4	0.4	0.4
Cast Iron	0.0	–	–	–	–	–

Y = coefficient having values as given in Table 304.1.1 for materials indicated and when t is less than $D/6$. For intermediate temperatures, the value of Y may be interpolated. When t is equal to or greater than $D/6$, $Y = \frac{d}{d+D}$

304.1.2 Straight Pipe Under Internal Pressure

(a) The internal pressure design thickness, t, shall be not less than that calculated by Equation 3a, when t is less than $D/6$:

$$t = \frac{PD}{2(SE+PY)} \qquad (3a)$$

Equations 3b and 3c may be used instead of Equation 3a:

$$t = \frac{PD}{2SE} \qquad (3b)$$

$$t = \frac{D}{2}\left(1 - \sqrt{\frac{SE-P}{SE+P}}\right) \qquad \text{(Lamé Equation)} \; (3c)$$

(b) Pipe with t equal to or greater than $D/6$, or P/SE greater than 0.385, requires special consideration, taking into account design and material factors such as theory of failure, fatigue and thermal stresses.

304.1.3 Straight Pipe Under External Pressure. For determining wall thickness and stiffening requirements for straight pipe under external pressure, the procedure outlined in paragraphs UG-28, UG-29 and UG-30 of Section VIII, Division 1 of the ASME Code shall be followed with the following exception. In determining P_{a2} for cylinders (pipe) having $D/t <$ 10,[1] S shall be lesser of 1-1/2 times the basic allowable stress value at design temperature from Appendix A of this Code (see Appendix A, Note 16) or 0.9 times the tabulated yield strength of the material at design temperature.

304.2 Curved and Mitered Segments of Metallic Piping

304.2.1 Pipe Bends. The minimum required thickness, t_m, of a bend, after bending, shall be determined as for straight pipe in accordance with 304.1.

304.2.2 Elbows. Manufactured elbows not in accordance with 303 shall meet the requirements of 304.7.

[1] The symbol D is equivalent to the symbol D_O of ASME Code Section VIII.

304.2.3 Miter Bends. An angular offset of 3 deg or less (angle α in Fig. 304.2.3) does not require design consideration as a miter bend. Acceptable methods for pressure design of multiple and single miter bends are given in 304.2.3(a) and (b).

(a) *Multiple Miter Bends:* The maximum allowable internal pressure shall be the lesser value calculated from Equations 4a and 4b. These equations are not applicable when θ exceeds 22.5 deg.

$$P_m = \frac{SE(T-c)}{r_2}\left[\frac{T-c}{(T-c) + 0.643 \tan\theta \sqrt{r_2(T-c)}}\right] \qquad (4a)$$

$$P_m = \frac{SE(T-c)}{r_2}\left(\frac{R_1 - r_2}{R_1 - 0.5\, r_2}\right) \qquad (4b)$$

(b) *Single Miter Bends*

(1) The maximum allowable internal pressure for a single miter bend with angle θ greater than 22.5 deg shall be calculated by Equation 4c:

(2) The maximum allowable internal pressure for a single miter bend with angle θ greater than 22.5 deg shall be calculated by Equation 4c:

$$P_m = \frac{SE(T-c)}{r_2}\left[\frac{T-c}{(T-c) + 1.25 \tan\theta \sqrt{r_2(T-c)}}\right] \qquad (4c)$$

(c) The following nomenclature is used in Equations 4a, 4b, and 4c for the pressure design of miter bends:

c = same as defined in 304.1.1

P_m = maximum allowable internal pressure for miter bends

r_2 = mean radius of pipe using nominal wall $\bar{T}$

R_1 = effective radius of miter bend, defined as the shortest distance from the pipe centerline to the intersection of the planes of adjacent miter joints

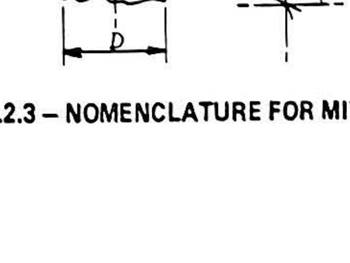


FIG. 304.2.3 – NOMENCLATURE FOR MITER BENDS

Sample Problem

Program: TI-59-11.3

THRD = 1 (yes)
PSI = 450 psig
SMAX = 20,000 psig
DEG = 650°F
MATL = Ferritic steel (Code = 1)
CORR = 0.063"

Step	Input	Key Stroke	Display	Printer		Comments
1		E	0.			Initialize program.
2	1	A	1.	1.	THRD	Stores THRD in R01.
3	450	A	450.	450.	PSI	Stores PSI in R02.
4	20000	A	20000.	20000.	SMAX	Stores SMAX in R03.
5	650	A	650.	650.	DEG	Stores DEG in R04.
6	1	A	1.	1.	MATL	Stores MATL ion R05.
7	.063	A	0.063	0.063.	CORR	Stores CORR in R06.
8		B	0.	SMLS		The program first calculates the value of Y and stores it in R14. Then for each value of OD that is stored in memory, the program calculates the minimum wall thickness using Equation 3a. The thread allowance, corrosion allowance, and mill tolerance are added, as needed. For each case, the nominal pipe size and minimum wall thickness are printed. The program continues until 1/2" to 36" pipe sizes have been analyzed.
				0.5		
				0.1513	T	
				0.75		
				0.1540	T	
				1.		
				0.1745	T	
				1.5		
				0.1819	T	
				2.		
				0.1880	T	
				3.		
				0.1166	T	
				4.		
				0.1293	T	
				6.		
				0.1564	T	
				8.		
				0.1819	T	
				10.		
				0.2090	T	
				12.		

Step	Input	Key Stroke	Display	Printer		Comments
				0.2345	T	
				14.		
				0.2504	T	
				16.		
				0.2759	T	
				18.		
				0.3014	T	
				20.		
				0.3268	T	
				24.		
				0.3778	T	
				30.		
				0.4543	T	
				36.		
				0.5307	T	

Coding Form

Program Number TI-59-11.3 **Title** Pipe Thickness Array

Loc	Code	Key	Comments
000	05	5	Initialize program. RST resets all flags to "OFF." Loads pointers for input routine.
001	03	3	
002	42	STO	
003	09	09	
004	00	0	
005	42	STO	
006	00	00	
007	42	STO	
008	14	14	
009	91	R/S	
010	76	LBL	
011	15	E	
012	81	RST	
013	76	LBL	Input routine uses R00 and R09 as pointers.
014	11	A	
015	69	OP	
016	20	20	
017	69	OP	
018	29	29	
019	72	ST*	
020	00	00	
021	32	X:T	
022	73	RC*	
023	09	09	
024	69	OP	
025	04	04	
026	32	X:T	
027	69	OP	
028	06	06	
029	91	R/S	
030	76	LBL	Main equation subroutine. Performs Equation 3a. Flag 1 is set if the class is threaded. Thread allowance is in R12.
031	16	A'	
032	99	PRT	
033	87	IFF	
034	01	01	
035	33	X²	
036	00	0	
037	42	STO	
038	12	12	
039	76	LBL	
040	33	X²	
041	43	RCL	
042	02	02	
043	65	×	
044	73	RC*	
045	08	08	
046	55	÷	
047	02	2	
048	55	÷	
049	53	(	
050	43	RCL	
051	03	03	
052	85	+	
053	43	RCL	
054	02	02	
055	65	×	
056	43	RCL	
057	14	14	R06 contains the corrosion allowance.
058	54	)	
059	85	+	

Loc	Code	Key	Comments
060	43	RCL	
061	06	06	
062	85	+	
063	43	RCL	
064	12	12	
065	54	)	
066	87	IFF	
067	02	02	
068	70	RAD	
069	65	×	Flag 2 is set for plate analysis.
070	08	8	
071	55	÷	
072	07	7	
073	61	GTO	
074	80	GRD	
075	76	LBL	
076	70	RAD	
077	85	+	
078	93	.	
079	00	0	
080	01	1	
081	76	LBL	
082	80	GRD	
083	95	=	
084	32	X:T	
085	58	FIX	
086	04	04	
087	03	3	Prints pipe thickness.
088	07	7	
089	69	OP	
090	04	04	
091	32	X:T	
092	69	OP	
093	06	06	
094	69	OP	
095	28	28	
096	22	INV	
097	58	FIX	
098	92	RTN	
099	76	LBL	First test to assign value of Y. This section determines if Y = 0.4 or Y = 0.7.
100	17	B'	
101	08	8	
102	09	9	
103	09	9	
104	32	X:T	
105	43	RCL	
106	04	04	
107	22	INV	
108	77	GE	
109	24	CE	
110	01	1	All temperatures are normalized.
111	00	0	
112	00	0	
113	01	1	
114	32	X:T	
115	43	RCL	
116	04	04	
117	77	GE	
118	29	CP	
119	09	9	

Loc	Code	Key	Comments
120	05	5	Tests to see if temperature > 950 °F (normalized).
121	00	0	
122	32	X:T	
123	43	RCL	
124	04	04	
125	77	GE	
126	19	D'	
127	09	9	Interpolation routine between temperature = 900°F and = 950°F.
128	05	5	
129	00	0	
130	75	-	
131	43	RCL	
132	04	04	
133	54	)	
134	65	×	
135	93	.	y is between 0.4 and 0.5.
136	00	0	
137	00	0	
138	02	2	
139	94	+/-	
140	85	+	
141	93	.	
142	05	5	
143	95	=	
144	42	STO	
145	14	14	
146	61	GTO	
147	10	E'	
148	76	LBL	Interpolation routine between temperature = 950°F and temperature = 1000°F.
149	19	D'	
150	01	1	
151	00	0	
152	00	0	
153	00	0	
154	75	-	
155	43	RCL	
156	04	04	
157	54	)	
158	65	×	
159	93	.	
160	00	0	
161	00	0	
162	04	4	
163	94	+/-	
164	85	+	
165	76	LBL	
166	29	CP	If temperature > 1000°F Y = 0.7.
167	93	.	
168	07	7	
169	95	=	
170	42	STO	
171	14	14	
172	61	GTO	
173	10	E'	
174	76	LBL	If temperature ≤ 900°F Y = 0.4.
175	24	CE	
176	93	.	
177	04	4	
178	42	STO	
179	14	14	

Loc	Code	Key	Comments
180	76	LBL	Skips to PRD for plate analysis.
181	10	E'	
182	87	IFF	
183	02	02	
184	49	PRD	
185	14	D	
186	76	LBL	Main control for seamless analysis. Prints "SMLS."
187	12	B	
188	98	ADV	
189	86	STF	
190	40	IND	
191	01	01	
192	02	2	
193	32	X:T	
194	43	RCL	
195	30	30	
196	69	OP	
197	00	00	
198	69	OP	
199	02	02	
200	69	OP	
201	05	05	
202	69	OP	
203	00	00	
204	98	ADV	
205	76	LBL	Determines material type.
206	57	ENG	
207	02	2	
208	32	X:T	
209	43	RCL	
210	05	05	
211	67	EQ	
212	34	√X	
213	77	GE	
214	35	1/X	
215	61	GTO	
216	68	NOP	
217	76	LBL	Normalizes material temperatures to carbon steel. Temperature for material #3 is reduced by 600°F to insure Y = 0.4.
218	34	√X	
219	01	1	
220	05	5	
221	00	0	
222	61	GTO	
223	44	SUM	
224	76	LBL	
225	35	1/X	
226	32	X:T	
227	04	4	
228	67	EQ	
229	14	D	
230	06	6	
231	00	0	
232	00	0	
233	76	LBL	
234	44	SUM	
235	94	+/-	
236	44	SUM	
237	04	04	
238	76	LBL	Calls routine to determine Y value.
239	68	NOP	

Loc	Code	Key	Comments
240	17	B'	
241	87	IFF	
242	02	02	
243	49	PRD	
244	76	LBL	Begin array analysis for seamless pipe. Adjust thread allowance (R12).
245	14	D	
246	93	.	
247	00	0	
248	06	6	
249	42	STO	
250	12	12	
251	03	3	
252	02	2	
253	42	STO	
254	08	08	
255	93	.	
256	05	5	
257	16	A'	
258	93	.	
259	07	7	
260	05	5	
261	16	A'	
262	93	.	
263	00	0	
264	07	7	
265	05	5	
266	42	STO	
267	12	12	
268	01	1	
269	16	A'	
270	01	1	
271	93	.	
272	05	.5	
273	16	A'	
274	02	2	
275	32	X:T	
276	43	RCL	
277	05	05	If material is stainless steel, zero out thread allowance for 2" size.
278	22	INV	
279	67	EQ	
280	28	LOG	
281	00	0	
282	42	STO	
283	12	12	
284	76	LBL	
285	28	LOG	
286	02	2	
287	16	A'	
288	01	1	
289	00	0	
290	42	STO	
291	00	00	
292	00	0	
293	42	STO	This routine skips certain sizes of pipe.
294	12	12	
295	76	LBL	
296	23	LNX	
297	73	RC*	
298	08	08	
299	59	INT	

Loc	Code	Key	Comments
300	16	A'	
301	97	DSZ	
302	00	00	
303	23	LNX	
304	69	OP	
305	28	28	
306	02	2	
307	04	4	
308	16	A'	
309	02	2	
310	44	SUM	
311	08	08	
312	03	3	
313	00	0	
314	16	A'	
315	69	OP	
316	28	28	
317	03	3	
318	06	6	
319	16	A'	
320	61	GTO	
321	48	EXC	
322	76	LBL	Begin array analysis for plate-fabricated pipe. Array starts @ 16" pipe.
323	49	PRD	
324	00	0	
325	42	STO	
326	12	12	
327	01	1	
328	00	0	
329	42	STO	
330	00	00	
331	04	4	
332	04	4	
333	42	STO	
334	08	08	
335	76	LBL	
336	60	DEG	
337	73	RC*	
338	08	08	
339	16	A'	
340	97	DSZ	
341	00	00	
342	60	DEG	
343	76	LBL	End of program.
344	48	EXC	
345	98	ADV	
346	98	ADV	
347	98	ADV	
348	98	ADV	
349	81	RST	
350	76	LBL	Main control for plate analysis.
351	13	C	
352	98	ADV	
353	86	STF	
354	02	02	
355	43	RCL	
356	31	31	
357	69	OP	
358	00	00	
359	69	OP	

Loc	Code	Key	Comments
360	02	02	
361	69	DP	Prints "PLATE."
362	05	05	
363	69	DP	
364	00	00	
365	98	ADV	
366	61	GTO	
367	57	ENG	

The following data must be stored in memory and then recorded onto a magnetic card (side 3).

36302736.	30
3327133717.	31
0.84	32
1.05	33
1.315	34
1.9	35
2.375	36
3.5	37
4.5	38
6.625	39
8.625	40
10.75	41
12.75	42
14.	43
16.	44
18.	45
20.	46
22.	47
24.	48
26.	49
28.	50
30.	51
32.	52
36.	53
37233516.	54
333624.	55
36301344.	56
161722.	57
30133727.	58
15323535.	59

Loc	Code	Key	Comments	Loc	Code	Key	Comments

Program HP-41CV-11: Pipe Wall Thickness by Class and Single OD, and Maximum Allowable Working Pressure

Introduction:

HP-41CV-11 performs three separate functions. First, it determines the pipe wall thicknesses for an entire class from 1/2-in to 36-in pipe size for seamless pipe, and 16-in to 36-in for pipe fabricated from plate. Second, it determines the pipe wall thickness for an individual outside diameter that is input by the user. This may be done for seamless pipes as well as those fabricated from plates. Third, the maximum allowable working pressure can be calculated for the input values of outside diameter and nominal thickness. The program calculates the Y factor based on temperature; assigns the correct value for thread allowance, if the input calls for threads; and adds the corrosion allowance and the mill tolerance. The program uses the equations found in ASME/ANSI B31.3, 1980.

Nomenclature:

Up to eight items are input for any of the three analyses:

STRESS:	Allowable stress (psi)
TEMP(F):	Design temperature (°F)
CORR:	Corrosion allowance (in)
MATERIAL:	Material code
	CS = Ferritic steel
	SS = Austenitic steel
	DM = Other ductile materials
	CI = Cast iron
THREADED:	Thread flag (Y or N)
SEAMLESS:	Seamless flag (Y or N)
PRESSURE:	Design pressure (psig)
OD:	Pipe outside diameter (in)
T:	Pipe nominal wall thickness (in)

The program calculates or assigns the following data:

Y:	Y factor from Table 304.1.1 in ASME/ANSI B31.3
Thread allowance:	0.060 in for 1/2 in and 3/4 in
	0.075 in for 1 in to 2 in
Mill tolerance:	12½ percent for seamless pipe
	0.01 in for plate-fabricated pipe

Method:

The equation used for minimum allowed wall thickness to contain internal pressure is Equation 3a from Section 304.1.2 of ASME/ANSI B31.3, 1980. The corrosion allowance, thread allowance, and mill tolerance are added, according to the input.

Equation 3a $$t' = \frac{(P)(D)}{2(SE + PY)}$$

For the maximum allowable working pressure calculations, the equation is the mirror image of Equation 3a. Given a nominal wall thickness for a distinct outside diameter, the program calculates the maximum pressure that can be sustained by the nominal wall:

MAWP $$p = \frac{(SE)(2t')}{(D)} \times \frac{1}{1 - (2Yt'/D)}$$

t' is the corroded wall thickness, less the mill tolerance and thread allowance.

The following data is defined:

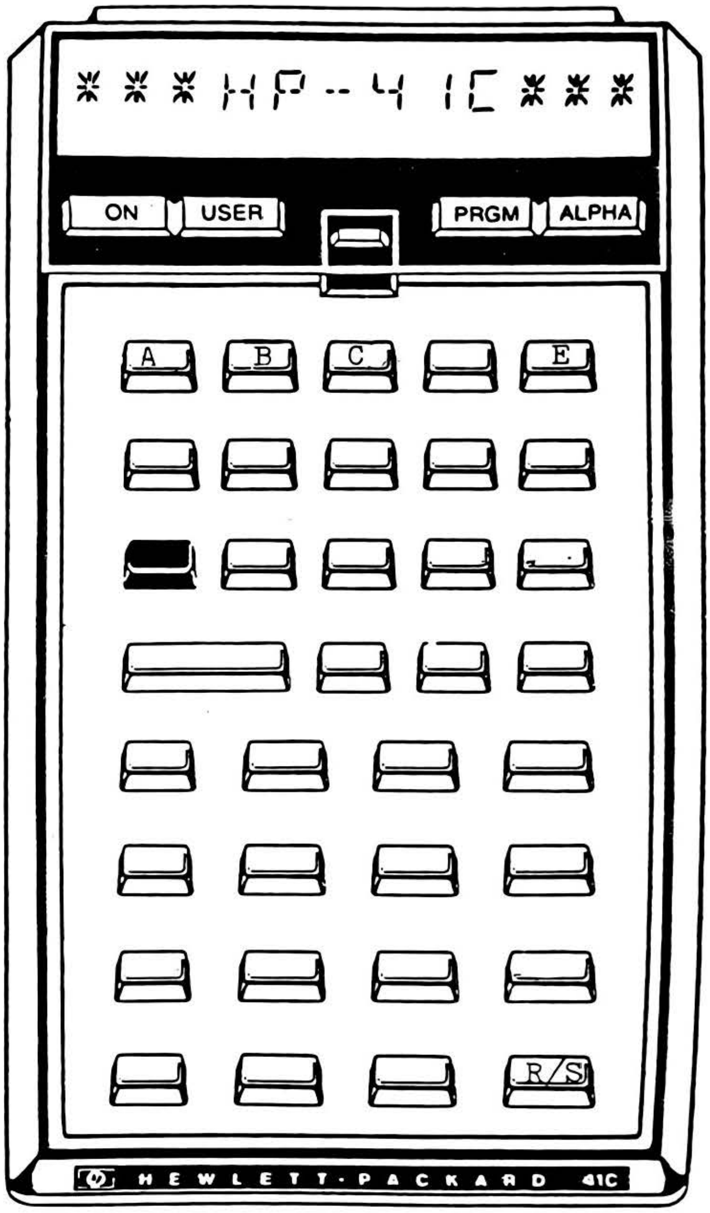
P:	Design pressure (psig)
D:	Outside diameter (in)
S:	Allowable stress (psi)
E:	Joint efficiency factor
Y:	Y factor from Table 304.1.1

Limitations:

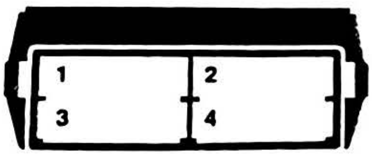
The program selectively analyzes certain pipe sizes in the class arrays. Those sizes *not* analyzed are: 2½ in, 3½ in, 5 in, 22 in, 26 in, 28 in, 32 in, or 34 in for the seamless class. The 34-in size is omitted from the plate classes. Only 12½ percent mill tolerance is used for seamless pipe, and only 0.01 in mill tolerance is used for pipe fabricated from plate. The program does not check to see if the wall thickness is greater than OD/6, nor does it check for a temperature limitation for cast iron. Only English units may be used.

Keyboard Card Labeling

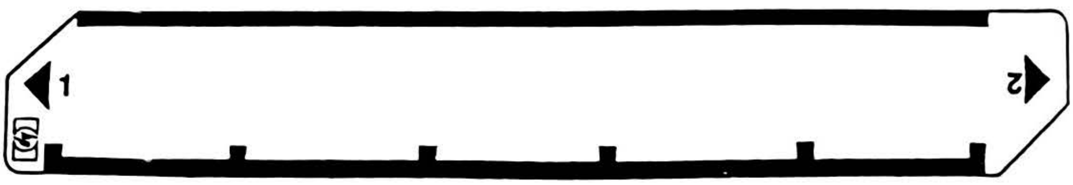
KEYBOARD



SYSTEM CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-11 **Title** Pipe Wall Thickness

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards.			
2	Initialize program.		E	CARD
3	Read in data card.*			STRESS=
4	Input stress value.	STRESS	R/S	TEMP(F)=
5	Input design temperature.	TEMP	R/S	CORR=
6	Input corrosion allowance.	CORR	R/S	MATERIAL=
7	Input material designation.	MATL	R/S	THREADED?
8	Answer "threaded" prompt.	Y or N	R/S	SEAMLESS?
9	Answer "seamless" prompt.	Y or N	R/S	ANALYSIS. . .
10	Choose analysis:			
	Class Array		A	PRESSURE=
11	Input design pressure.	PRESS	R/S	
	Single OD		B	PRESSURE=
11	Input design pressure.	PRESS	R/S	OD=
12	Input outside diameter.	OD	R/S	
	MAWP		C	OD=
11	Input outside diameter.	OD	R/S	T=
12	Input nominal pipe thickness.	T	R/S	

* This step is only necessary if the data card has not been read in previously. The program will only prompt if the data is not in memory.

Registers, Flags, Assignments

Program Number HP-41CV-11 Title Pipe Wall Thickness

DATA REGISTERS

00	Indirect Register	
01	STRESS	
02	TEMP	
03	CORR	
04	MATL	
05	THREADED?	
06	SEAMLESS?	
07	PRESSURE	
08	OD	
09	T	
10	"1/2"	
11	"3/4"	
12	"1"	
13	"1-1/2"	
14	Thread Allowance	
15	Y	
16	Indirect register	
17	PRESSURE (MWAP analysis)	
18		
19		
20	t'	
21		
22		
23		
24		
25		
26		
27	" "	
28	0.84	
29	1.05	
30	1.315	
31	1.9	
32	2.375	To be recorded on
33	3.5	magnetic cards
34	4.5	
35	6.625	
36	8.625	
37	10.75	
38	12.75	

DATA REGISTERS

39	14	
40	16	
41	18	
42	20	
43	22	To be recorded on
44	24	magnetic cards
45	26	
46	28	
47	30	
48	32	
49	36	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates
1	C	Threaded pipe	
2	C	Plate-fabricated pipe	
3	C	Single OD analysis	

ASSIGNMENTS

Label	Key	Function	Key
WLT	E (15)		
CLAS	A (11)		
OD	B (12)		
MAWP	C (13)		

	Example 1	Example 2	Example 3
STRESS=	20,000.000	20,000.000	20,000.000
TEMP(F)=	650.000	650.000	650.000
CORR=	0.063	0.063	0.063
MATERIAL=	CS	CS	SS
THREADED?	N	Y	Y
SEAMLESS?	Y	Y	Y
PRESSURE=	450.000	450.000	450.000

CLASS ARRAY

SEAMLESS

IPS	T (Example 1)	T (Example 2)	T (Example 3)
1/2	0.083	0.151	0.151
3/4	0.085	0.154	0.154
1	0.089	0.174	0.174
1-1/2	0.096	0.182	0.182
2	0.102	0.188	0.102
3.	0.117	0.117	0.117
4.	0.129	0.129	0.129
6.	0.156	0.156	0.156
8.	0.182	0.182	0.182
10.	0.209	0.209	0.209
12.	0.234	0.234	0.234
14.	0.250	0.256	0.250
16.	0.276	0.276	0.276
18.	0.301	0.301	0.301
20.	0.327	0.327	0.327
24.	0.378	0.378	0.378
30.	0.454	0.454	0.454
36.	0.531	0.531	0.531

Example 1 is an unthreaded class of carbon steel pipe at 650°F, 450 psig design pressure, with an allowable stress of 20,000 psi and a corrosion allowance of 0.063″. It is a seamless class.

Example 2 is the same class of pipe as Example 1, except that it is a threaded class.

Example 3 has the same design conditions as the two previous examples but it is a stainless steel class. Note that the 2″ size is not threaded.

Example 4

```
STRESS= 20,000.000
TEMP(F)= 1,950.000
CORR= 0.063
MATERIAL=DM
THREADED?Y
SEAMLESS?Y
PRESSURE= 450.000

CLASS ARRAY
SEAMLESS
          IPS          T

          1/2      0.151
          3/4      0.154
            1      0.174
        1-1/2      0.182
            2      0.188
           3.      0.117
           4.      0.129
           6.      0.156
           8.      0.182
          10.      0.209
          12.      0.234
          14.      0.253
          16.      0.276
          18.      0.301
          20.      0.327
          24.      0.378
          30.      0.454
          36.      0.531
```

Example 5

```
STRESS= 20,000.000
TEMP(F)= 650.000
CORR= 0.063
MATERIAL=CI
THREADED?Y
SEAMLESS?Y
PRESSURE= 450.000

CLASS ARRAY
SEAMLESS
          IPS          T

          1/2      0.151
          3/4      0.154
            1      0.175
        1-1/2      0.182
            2      0.188
           3.      0.117
           4.      0.130
           6.      0.157
           8.      0.183
          10.      0.210
          12.      0.236
          14.      0.252
          16.      0.278
          18.      0.303
          20.      0.329
          24.      0.381
          30.      0.458
          36.      0.535
```

Example 6

```
STRESS= 15,000.000
TEMP(F)= 950.000
CORR= 0.125
MATERIAL=CS
THREADED?N
SEAMLESS?N
PRESSURE= 450.000

CLASS ARRAY
PLATE
          IPS          T

          16.      0.371
          18.      0.401
          20.      0.431
          22.      0.460
          24.      0.490
          26.      0.519
          28.      0.549
          30.      0.578
          32.      0.608
          36.      0.667
```

Example 4 is a class of materials that the B31.3 code designates "other ductile materials." It has the same conditions as the former examples, except that the temperature is 1950°F. This is to show that for this material class, the value of Y is always 0.4.

Example 5 is a cast iron class. For this material, Y is always 0.0.

Example 6 is a piping class of plate-fabricated pipe at 950°F, 450 psig design pressure, a corrosion allowance of 0.125" and a design stress of 15,000 psi. The value of Y is calculated by the program and is equal to 0.5.

Example 7

```
STRESS= 20,000.000
TEMP(F)= 650.000
CORR= 0.063
MATERIAL=CS
THREADED?N
SEAMLESS?Y
PRESSURE= 450.000
OD= 8.625

SINGLE OD
SEAMLESS
                0.182 T
```

Example 8

```
STRESS= 15,000.000
TEMP(F)= 950.000
CORR= 0.125
MATERIAL=CS
THREADED?N
SEAMLESS?N
PRESSURE= 450.000
OD= 16.000

SINGLE OD
PLATE
                0.371 T
```

Example 9

```
STRESS= 20,000.000
TEMP(F)= 650.000
CORR= 0.063
MATERIAL=CS
THREADED?N
SEAMLESS?Y
OD= 8.625
T= 0.182

MAWP
SEAMLESS
            450.398 PSI
```

Example 10

```
STRESS= 15,000.000
TEMP(F)= 950.000
CORR= 0.125
MATERIAL=CS
THREADED?N
SEAMLESS?N
OD= 16.000
T= 0.371

MAWP
PLATE
            449.125 PSI
```

Examples 7 and 8 are analyses of specific pipe sizes, and not arrays. The design conditions are the same as the previous examples.

Examples 9 and 10 are Maximum Allowable Working Pressure calculations. This analysis performs the opposite function from that of the other analyses. The design conditions are exactly those of Examples 7 and 8.

t': Minimum wall thickness to contain internal pressure (in)
P: Design pressure (psig)
D: Outside diameter (in)
S: Allowable stress at design pressure (psi)
E: Joint efficiency factor
y: Pressure factor at design temperature from Table 304.1.1

$$t' = \frac{(P)(D)}{2(SE + Py)}$$

$$\frac{(450)(8.625)}{2(20000 + (450)(0.4))} = 0.096''$$

$$(0.096 + 0.063) \times (8/7) = 0.182''$$

$$\frac{(450)(16)}{2(15000 + (450)(0.5))} = 0.236''$$

$$(0.236 + 0.125 + 0.01) = 0.371''$$

Maximum Allowable Working Pressure

$$\text{MAWP} = \frac{(SE)(2t')}{(D)} \times \frac{1}{1 - (2y')/(D)}$$

$$\frac{(20{,}000)(2)((0.182)(7/8) - 0.063)}{(8.625)} \times \frac{1}{1 - ((0.182)(7/8) - 0.063)/(8.625)}$$

$$= 450.398 \text{ psi}$$

$$\frac{(15000)(2)(0.371 - 0.125 - .01)}{(16)} \times \frac{1}{1 - (0.371 - .125 - .01)/(16)}$$

$$= 449.125 \text{ psi}$$

Sample Problem

Program: HP-41CV-11 Title Pipe Wall Thickness

Sample Problem (Sketch if Desired)

PRESSURE = 450 psig
TEMP <F> = 650 °F
CORR = 0.063"
MATERIAL = Carbon steel
STRESS = 20,000 psi
The class is threaded and seamless.

Input	Function	Display	Comments
	E	STRESS=	Initializes program. Stores the alpha labels for pipe sizes 1/2" to 1 1/2". Because the data card has been read into memory once, the program skips over the prompt for the data card. The prompt for the allowable stress is the first of the input sequence.
20,000	R/S	TEMP(F)=	Stores STRESS in R01. The program uses IN to input numeric data.
650	R/S	CORR=	Stores TEMP <F> in R02, using IN, a subroutine.
.063	R/S	MATERIAL=	Stores CORR in R03, using IN, a subroutine.
"CS" (no quotes)	R/S	THREADED?	The program turns on the alpha mode for the material input. Stores CS in R04.
"Y"	R/S	SEAMLESS?	Stores Y in R05, using INAL, the subroutine used to input alpha data.
"Y"	R/S	ANALYSIS...	Stores Y in R06, using INAL. The program sets Flag 1 because the input is threaded. Flag 2 is left clear because the answer to the seamless prompt was Y. A 1 (numer - ic) is stored in R04, because the alpha input CS is in R04. The program prompts for which analysis is to be performed. Up to this point, all the input can apply to any of the three analyses.
		PRESSURE=	
450	R/S		PRESS is stored in R07.

Input	Function	Display	Comments
	A	(Printed output) CLASS ARRAY SEAMLESS IPS T 1/2 0.151 3/4 0.154 1 0.174 1-1/2 0.182 2 0.188 3. 0.117 4. 0.129 6. 0.156 8. 0.182 10. 0.209 12. 0.234 14. 0.250 16. 0.276 18. 0.301 20. 0.327 24. 0.378 30. 0.454 36. 0.531	The program begins the class array analysis. The pipe sizes 1/2" through 2" are executed using WL1, a subroutine, which is a subset of WL, a subroutine. The correct values for thread allowance are input to R14, by the program: 0.06" for 1/2" and 3/4", and 0.075" for 1" through 2". The 2" size *is* threaded because it is *not* a stainless material. The alpha labels for these sizes are stored in memory and are used by the program for printout. For the sizes 3" to 20", the routine WL is used. This routine uses the integer value of the pipe outside diameter for the printout. The program then performs the calculation for 24", 30", and 36" pipe sizes, skipping the sizes in between.

Coding Form

Program Number HP-41CV-11 Title Pipe Wall Thickness

Step/Line	Key Entry	Key Code	Comments
01	♦LBL "WLT"		Initialize program. Clear any flags set by the program. Store alpha labels for class array.
02	CLA		
03	CF 01		
04	CF 02		
05	CF 03		
06	FIX 3		
07	"1/2"		
08	ASTO 10		
09	"3/4"		
10	ASTO 11		
11	"1"		
12	ASTO 12		
13	"1-1/2"		
14	ASTO 13		
15	RCL 28		Check if data is stored in memory. If not, prompt for user to read in data card.
16	X≠0?		
17	GTO 10		
18	27.049		
19	"DATA CARD"		
20	RDTAX		
21	♦LBL 10		General input section. All input will apply to any analysis.
22	1		
23	STO 00		
24	"STRESS="		
25	XEQ "IN"		
26	"TEMP(F)="		
27	XEQ "IN"		
28	"CORR="		
29	XEQ "IN"		
30	"MATERIAL="		
31	XEQ "INAL"		
32	"THREADED?"		
33	XEQ "INAL"		
34	"SEAMLESS?"		
35	XEQ "INAL"		
36	"Y"		This section sets the threaded pipe flag and plate-fabricated pipe flag, according to input values.
37	ASTO 17		
38	RCL 17		
39	RCL 05		
40	X=Y?		
41	SF 01		
42	CLX		
43	RCL 06		
44	X≠Y?		
45	SF 02		
46	"CS"		This section stores a material code in R04 using MATERIAL: 1 for carbon steel
47	1		
48	XEQ "MTL"		
49	"SS"		

Step/Line	Key Entry	Key Code	Comments
50	2		2 for stainless steel 3 for ductile material 4 for cast iron
51	XEQ "MTL"		
52	"DM"		
53	3		
54	XEQ "MTL"		
55	"CI"		
56	4		
57	XEQ "MTL"		
58	"ANALYSIS..."		Program stops to prompt user for analysis.
59	PROMPT		
60	♦LBL "CLAS"		Class array analysis. Prompt for design pressure.
61	"PRESSURE="		
62	XEQ "IN"		
63	ADV		Print analysis label. Call subroutines to adjust temperature and calculate Y.
64	SF 12		
65	"CLASS ARRAY"		
66	PRA		
67	CF 12		
68	XEQ "T"		
69	XEQ "Y"		
70	FS? 02		Skip to plate analysis.
71	GTO "PL"		
72	"SEAMLESS"		Print seamless label. Print header for array.
73	PRA		
74	"IPS"		
75	ARCL 27		
76	"├ T"		
77	ACA		
78	ADV		
79	CLA		
80	ADV		Set thread allowance for ½″ and ¾″ pipe. Execute the pipe thickness routine for ½″ and ¾″ pipe. If the class is not threaded, WL1 will omit the thread allowance.
81	28.1		
82	STO 16		
83	.06		
84	STO 14		
85	10.011		
86	STO 00		
87	♦LBL "AC"		
88	ARCL IND 00		
89	ACA		
90	CLA		
91	XEQ "WL1"		
92	ISG 00		Set thread allowance for 1″ through 2″ pipe.
93	GTO "AC"		
94	.075		
95	STO 14		
96	12.013		Execute the pipe thickness routines for 1″ and 1½″ pipe.
97	STO 00		
98	♦LBL "AD"		

Step/Line	Key Entry	Key Code	Comments
99	ARCL IND 00		
100	ACA		
101	CLA		
102	XEQ "WL1"		
103	ISG 00		If the class is a stainless class, the thread allowance is omitted. Execute the pipe thickness routine for 2″ pipe.
104	GTO "AD"		
105	RCL 04		
106	2		
107	X≠Y?		
108	GTO 11		
109	0		
110	STO 14		
111	♦LBL 11		
112	"2"		
113	ACA		
114	CLA		
115	XEQ "WL1"		
116	0		Continue the class array analysis for 3″ pipe through 20″ pipe.
117	STO 14		
118	33.042		
119	STO 00		
120	♦LBL "AE"		
121	XEQ "WL"		
122	ISG 00		
123	GTO "AE"		
124	44		Execute the routine for 24″ pipe.
125	STO 00		
126	44.1		
127	STO 16		
128	XEQ "WL"		
129	47		Execute the routine for 30″ pipe.
130	STO 00		
131	47.1		
132	STO 16		
133	XEQ "WL"		
134	49		Execute the routine for 36″ pipe.
135	STO 00		
136	49.1		
137	STO 16		
138	XEQ "WL"		
139	ADV		End class array analysis.
140	ADV		
141	CLX		
142	STOP		
143	♦LBL "PL"		Class array analysis for plate-fabricated pipe. Print "PLATE" and header for array.
144	"PLATE"		
145	PRA		
146	"IPS"		
147	ARCL 27		

Step/Line	Key Entry	Key Code	Comments
148	"⊦ T"		
149	ACA		
150	ADV		
151	ADV		Execute pipe thickness routine for 16" pipe to 36" pipe.
152	CLA		
153	40.1		
154	STO 16		
155	40.049		
156	STO 00		
157	0		
158	STO 14		
159	♦LBL "BA"		
160	XEQ "WL"		
161	ISG 00		
162	GTO "BA"		
163	ADV		End of class array analysis.
164	ADV		
165	CLX		
166	STOP		
167	♦LBL "OD"		Single OD analysis. Prompt for design pressure.
168	8		
169	STO 00		
170	"PRESSURE="		
171	XEQ "IN"		
172	"OD="		
173	XEQ "IN"		
174	"SINGLE OD"		Print analysis label.
175	SF 12		
176	ADV		
177	PRA		
178	CF 12		
179	CLA		
180	XEQ "T"		Execute routines for temperature, Y, and thread allowance.
181	XEQ "Y"		
182	XEQ "TH"		
183	FS? 02		If the pipe is seamless, print label. If plate, go to B.
184	GTO B		
185	"SEAMLESS"		
186	PRA		
187	CLA		
188	GTO A		Skip to A.
189	♦LBL B		Print "PLATE."
190	"PLATE"		
191	PRA		
192	CLA		
193	♦LBL A		Execute pipe thickness routine for input value of OD. Flag 3 returns
194	SF 03		
195	9.1		
196	STO 16		

Step/Line	Key Entry	Key Code	Comments
197	XEQ "WL1"		from WL1 to a different printout.
198	ARCL X		
199	"⊦ T"		
200	ACA		
201	ADV		
202	CLX		End SINGLE OD analysis.
203	ADV		
204	ADV		
205	STOP		
206	♦LBL "MAWP"		MAWP analysis. Prompt for input of OD and nominal wall thickness.
207	8		
208	STO 00		
209	"OD="		
210	XEQ "IN"		
211	"T="		
212	XEQ "IN"		
213	XEQ "T"		Adjust temperature, calculate Y, calculate thread allowance.
214	XEQ "Y"		
215	XEQ "TH"		
216	SF 12		
217	"MAWP"		Print "MAWP."
218	ADV		
219	PRA		
220	CF 12		
221	FS? 02		If seamless pipe put "SEAMLESS" in alpha register and go to D.
222	GTO C		
223	"SEAMLESS"		
224	GTO D		
225	♦LBL C		If plate, put "PLATE" in alpha register.
226	"PLATE"		
227	♦LBL D		
228	PRA		Print alpha register. Recall nominal wall thickness.
229	CLA		
230	RCL 09		
231	FS? 02		
232	GTO 23		
233	7		Remove mill tolerance for seamless pipe.
234	*		
235	8		
236	/		
237	GTO 24		
238	♦LBL 23		Remove mill tolerance for plate pipe.
239	.01		
240	-		
241	♦LBL 24		Calculate maximum allowable working pressure; t is in R20.
242	RCL 03		
243	-		
244	RCL 14		
245	-		

Step/Line	Key Entry	Key Code	Comments
246	STO 20		
247	2		
248	*		
249	RCL 01		
250	*		
251	RCL 08		
252	/		
253	1		
254	RCL 20		
255	2		
256	*		
257	RCL 15		
258	*		
259	RCL 08		
260	/		
261	-		
262	1/X		
263	*		
264	STO 17		
265	ARCL 17		
266	"⊦ PSI"		
267	ACA		
268	ADV		
269	ADV		
270	ADV		
271	CLX		
272	STOP		
273	♦LBL "TH"		Calculates the thread allowance for the SINGLE OD and MAWP analyses.
274	RCL 29		
275	RCL 08		
276	X>Y?		
277	GTO 12		
278	.06		
279	STO 14		
280	GTO 13		
281	♦LBL 12		
282	RCL 32		
283	RCL 08		
284	X>Y?		
285	GTO 13		
286	.075		
287	STO 14		
288	RCL 32		Stainless steel does not have a thread allowance for 2" size.
289	RCL 08		
290	X≠Y?		
291	GTO 13		
292	2		
293	RCL 04		
294	X≠Y?		

Step/Line	Key Entry	Key Code	Comments
295	GTO 13		
296	0		
297	STO 14		
298	♦LBL 13		
299	RTN		
300	♦LBL "T"		If the material is stainless steel, the temperature is adjusted downward for Y calculation.
301	RCL 04		
302	2		
303	X≠Y?		
304	RTN		
305	150		
306	ST- 02		
307	RTN		
308	♦LBL "Y"		Calculates Y for pipe thickness routine. If cast iron, Y = 0.0.
309	RCL 04		
310	4		
311	X=Y?		
312	GTO 09		
313	CLX		If "ductile material," Y = 0.4 regardless of temperature.
314	3		
315	X=Y?		
316	GTO H		
317	RCL 02		If temperature is greater than 900°F (adjusted) go to 07.
318	900		
319	X<Y?		
320	GTO 07		
321	♦LBL H		If temperature is less than 900°F (adjusted), Y = 0.4.
322	.4		
323	STO 15		
324	RTN		
325	♦LBL 07		If temperature is less than 1000°F (adjusted) go to 08.
326	CLX		
327	1000		
328	X>Y?		
329	GTO 08		
330	.7		If temperature is greater than 1000°F, Y = 0.7.
331	STO 15		
332	RTN		
333	♦LBL 08		If temperature is between 950° and 1000°F go to 03.
334	RCL 02		
335	950		
336	X<=Y?		
337	GTO 03		
338	950		Interpolate for Y for temperatures between 900° and 950°F.
339	RCL 02		
340	-		
341	.002		
342	*		
343	CHS		

Step/Line	Key Entry	Key Code	Comments
344	.5		
345	+		
346	STO 15		
347	RTN		
348	♦LBL 03		Interpolate for Y for temperatures between 950° and 1000°F.
349	1000		
350	RCL 02		
351	-		
352	.004		
353	*		
354	CHS		
355	.7		
356	+		
357	STO 15		
358	RTN		
359	♦LBL 09		Y for cast iron is always 0.0.
360	0		
361	STO 15		
362	RTN		
363	♦LBL "MTL"		This routine sets a code for the four materials: 1 = Ferretic Steel 2 = Austenitic Steel 3 = "Ductile material" 4 = Cast iron Code is in R04.
364	ASTO 17		
365	RCL 17		
366	RCL 04		
367	X≠Y?		
368	RTN		
369	RCL Z		
370	STO 04		
371	RTN		
372	♦LBL "IN"		Input routine for numeric values. Prompts, prints, and increments pointer (R00).
373	PROMPT		
374	STO IND 00		
375	ACA		
376	ACX		
377	PRBUF		
378	1		
379	ST+ 00		
380	RTN		
381	♦LBL "INAL"		Input routine for alpha values. Prompts, prints, and increments pointer (R00).
382	ACA		
383	AON		
384	PROMPT		
385	CF 12		
386	ACA		
387	AOFF		
388	PRBUF		
389	ASTO IND 00		
390	1		
391	ST+ 00		
392	RTN		

Step/Line	Key Entry	Key Code	Comments
393	♦LBL "WL"		Routine that prints the pipe nominal size for the class array for sizes 3" and up.
394	RCL IND 00		
395	INT		
396	FIX 0		
397	ARCL X		
398	ACA		
399	FIX 3		
400	CLA		
401	♦LBL "WL1"		Calculates minimum wall thickness for internal pressure using Equation 3a in ANSI B31.3
402	RCL IND 16		
403	RCL 07		
404	*		
405	2		
406	/		
407	RCL 15		
408	RCL 07		
409	*		
410	RCL 01		
411	+		
412	/		
413	RCL 03		
414	+		
415	FC? 01		Skips thread allowance.
416	GTO F		
417	RCL 14		Adds thread allowance.
418	+		
419	♦LBL F		
420	FS? 02		
421	GTO 27		
422	8		Adds mill tolerance for seamless pipe.
423	*		
424	7		
425	/		
426	GTO 26		
427	♦LBL 27		Adds mill tolerance for plate-fabricated pipe.
428	.01		
429	+		
430	♦LBL 26		Prints nominal pipe size and minimum wall thickness for class array. For SINGLE OD, the routine returns to be printed by that analysis.
431	ISG 16		
432	FS? 03		
433	RTN		
434	ARCL 27		
435	ACA		
436	ACX		
437	ADV		
438	CLA		
439	RTN		
440	.END.		

Part **IV**

Special Applications

Chapter **12**

Turbo-machinery Loading Analysis per NEMA SM-23 and API-617

Program TI-59-12

Introduction:

TI-59-12 performs the individual nozzle loading analysis and the transformed casing loading analysis for steam-driven, single, and multistage turbines, set out in National Electrical Machinery Association's publication SM-23. The program also performs the analysis for centrifugal compressors from API-617. TI-59-12 performs the load transformations, calculates the allowables, and compares the applied loading with the allowables.

Nomenclature:

The user will input the coordinates of the individual nozzles, the applied loads, and the nominal diameter of the nozzle, using the following terms:

- D: Nozzle nominal diameter (in)
- ΔX: Distance from the reference nozzle to the individual nozzle along the X-axis (ft)
- ΔY: Same as above for the Y-axis (ft)
- ΔZ: Same as above for the Z-axis (ft)
- FX: Force applied to the individual nozzle in the X-direction (lb)
- FY: Same as above for the Y-direction (lb)
- FZ: Same as above for the Z-direction (lb)
- MX: Moment about the X-axis, applied to the individual nozzle (ft-lb)
- MY: Moment about the Y-axis, applied to the individual nozzle (ft-lb)
- MZ: Moment about the Z-axis, applied to the individual nozzle (ft-lb)
- TMX: Transferred moment due to FY and FZ (ft-lb)
- TMY: Transferred moment due to FX and FZ (ft-lb)
- TMZ: Transferred moment due to FX and FY (ft-lb)

The following user-keys execute the program:

- A: Input of data
- B: Execute individual nozzle analysis (NEMA)
- C: Execute individual nozzle analysis (API-617)
- D: Execute casing analysis (NEMA and API-617)
- E: Initialize

Method:

TI-59-12 calculates the "3F+M" value for the individual nozzle loading, determines the allowable, and expresses the difference between the two values as a percentage of the allowable. The nozzle loads are then transformed to the reference nozzle. The "force-induced" moments are printed for the user's information. (*Force-induced moments* are (TMX, TMY TMZ) moments about the reference nozzle due to the forces applied to the individual nozzles.) The final execution of the program prints the accumulated forces and moments at the reference nozzle along with their respective allowables. As before, the relationship between applied loads and allowables is expressed as a percentage of the allowable. The "2F+M" value is calculated and compared with its allowable.

Limitations

The program accepts an unlimited number of individual nozzles. All input must be done in English units. If an error in input is made, there is an error recovery key, E′. See user instructions for its use.

User Instructions

Program Number TI-59-12 **Title** Turbo-machinery Loading Analysis

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards.			
2	Initialize program (essential).		E	0
3	Input nominal diameter of nozzle.	D	A	D
4	Input nozzle X-coordinate.	ΔX	A	ΔX
5	Input nozzle Y-coordinate.	ΔY	A	ΔY
6	Input nozzle Z-coordinate.	ΔZ	A	ΔZ
7	Input FX.	FX	A	FX
8	Input FY.	FY	A	FY
9	Input FZ.	FZ	A	FZ
10	Input MX.	MX	A	MX
11	Input MY.	MY	A	MY
12	Input MZ.	MZ	A	MZ
	****If there is any error in input, use the error recovery key and repeat Steps 3 through 12.		2nd E	0
13	Perform individual nozzle analysis			
	NEMA		B	
	API-617		C	3F+M ALL %
14	Repeat Steps 3 through 13 for all nozzles, including the reference nozzle.			
15	Perform the casing analysis.		D	FX ALL % FY ALL % : : MZ ALL % 2F+M ALL %

Data Register Contents

REGI-STER	DATA	REGI-STER	DATA
00	DSZ	30	132727 "ALL"
01	D	31	
02	ΔX	32	
03	ΔY	33	
04	ΔZ	34	
05	FX	35	
06	FY	36	
07	FZ	37	
08	MX	38	
09	MY	39	
10	MZ	40	
11	3F + M allowable	41	
12	ΣD	42	
13	3F + M	43	
14	ΣFX	44	
15	ΣFY	45	
16	ΣFZ	46	
17	ΣMX	47	
18	ΣMY	48	
19	ΣMZ	49	
20	Alpha labels	50	
21	FX	51	
22	FY	52	
23	FZ Allowables	53	
24	MX	54	
25	MY	55	
26	MZ	56	
27	IND	57	
28	IND	58	
29	2F + M	59	

Example 1

TURBO-MACHINERY ANALYSIS

☒ NEMA ☐ API-617

PAGE 1

36.	D	Nominal diameter	10.	D
0.	ΔX	X-coordinate	2.0833	ΔX
0.	ΔY	Y-coordinate	-4.3333	ΔY
0.	ΔZ	Z-coordinate	** -2.5	ΔZ
0.	FX	X-nozzle force	-588.	FX
1697.	FY	Y-nozzle force	650.	FY
-815.	FZ	Z-nozzle force	-202.	FZ
-2938.	MX	X-nozzle moment	946.	MX
0.	MY	Y-nozzle moment	2737.	MY
0.	MZ	Z-nozzle moment	-293.	MZ
8586.	3F+M	Applied 3F+M	5609.	3F+M
8667.	ALL	Allowable 3F+M	4333.	ALL
99.	%	% applied/allowable	129.	%
0.	TMX	X-induced moment	2500.	TMX
0.	TMY	Y-induced moment	1891.	TMY
0.	TMZ	Z-induced moment	-1194.	TMZ
8.	D	Nominal diameter		
3.75	ΔX	X-coordinate		
-1.4583	ΔY	Y-coordinate		
-4.2188	ΔZ	Z-coordinate		
-10.	FX	X-nozzle force		
-43.	FY	Y-nozzle force		
-22.	FZ	Z-nozzle force		
129.	MX	X-nozzle moment		
-1517.	MY	Y-nozzle moment		
111.	MZ	Z-nozzle moment		
1674.	3F+M	Applied 3F+M		
4000.	ALL	Allowable 3F+M		
42.	%	% applied/allowable		
-149.	TMX	X-induced moment		
125.	TMY	Y-induced moment		
-176.	TMZ	Z-induced moment		

Example 1

TURBO-MACHINERY ANALYSIS

☒ NEMA ☐ API-617

PAGE 2

-598.	FX	Summed X-Forces at the reference nozzle
937.	ALL	Allowable FX
64.	%	% applied/allowable
2304.	FY	Summed Y-forces at the reference nozzle
2342.	ALL	Allowable FY
98.	%	% applied/allowable
-1039.	FZ	Summed Z-forces at the reference nozzle
1874.	ALL	Allowable FZ
55.	%	% applied/allowable
488.	MX	Summed X-moments at the reference nozzle
4684.	ALL	Allowable MX
10.	%	% applied/allowable
3236.	MY	Summed Y-moments at the reference nozzle
2342.	ALL	Allowable MY
138.	%	% applied/allowable
-1552.	MZ	Summed Z-moments at the reference nozzle
2342.	ALL	Allowable MZ
66.	%	% applied/allowable
8816.	2F+M	Applied 2F+M from the summed values listed above
4684.	ALL	Allowable 2F+M
188.	%	% applied/allowable

Nozzle 1

FX = 0	MX = −2938	$\Delta X = 0$
FY = 1697	MY = 0	$\Delta Y = 0$
FZ = −815	MZ = 0	$\Delta Z = 0$

De = (36 + 16)/3 = 17.333 : Allowable = 500(17.333) = 8667

$$3\sqrt{(0)^2 + (1697)^2 + (815)^2} \quad + \quad \sqrt{(2938)^2 + (0)^2 + (0)^2} = 8586$$

8586/8667 = 99%

NO MOMENTS TRANSFERRED

Nozzle 2

FX = −10	MX = 129	$\Delta X = 3.75$
FY = −43	MY = −1517	$\Delta Y = -1.4583$
FZ = −22	MZ = 111	$\Delta Z = -4.2188$

De = 8 : Allowable = 500(8) = 4000

$$3\sqrt{(10)^2 + (43)^2 + (22)^2} \quad + \quad \sqrt{(129)^2 + (1517)^2 + (111)^2} = 1674$$

1674/4000 = 42%

TMX = (−22)(−1.4583) − (−43)(−4.2188) = −149 ft-lb
TMY = (−10)(−4.2188) − (−22)(3.75) = 125 ft-lb
TMZ = (−43)(3.75) − (−10)(−1.4583) = −176 ft-lb

Nozzle 3

FX = −588	MX = 946	$\Delta X = 2.0833$
FY = 650	MY = 2737	$\Delta Y = -4.333$
FZ = −202	MZ = −293	$\Delta Z = -2.5$

De = (10 + 16)/3 = 8.667 : Allowable = 500(8.667) = 4333

$$3\sqrt{(588)^2 + (650)^2 + (202)^2} \quad + \quad \sqrt{(946)^2 + (2737)^2 + (293)^2} = 5609$$

5609/4333 = 129%

TMX = (−202)(−4.3333) − (650)(−2.5) = 2500 ft-lb
TMY = (−588)(−2.5) − (−202)(2.0833) = 1891 ft-lb
TMZ = (650)(2.0833) − (−588)(−4.3333) = −1194 ft-lb

$$Dc = (\sqrt{(36)^2 + (8)^2 + (10)^2} + 18)/3 = 18.737$$

$\underline{FX = 0 + (-10) + (-588) = -598}$

Allowable = 50Dc = 50(18.737) = 937

598/937 = 64%

$\underline{FY = (1697) + (-43) + (650) = 2304}$

Allowable = 125Dc = 125(18.737) = 2342

2304/2342 = 98%

$\underline{FZ = (-815) + (-22) + (-202) = -1039}$

Allowable = 100Dc = 100(18.737) = 1874

1039/1874 = 55%

$\underline{MX = (-2938) + 0 + (129) + (-149) + (946) + (2500) = 488}$

Allowable = 250Dc = 250(18.737) = 4684

488/4684 = 10%

$\underline{MY = 0 + 0 + (-1517) + (125) + (2737) + (1891) = 3236}$

Allowable = 125Dc = 125(18.737) = 2342

3236/2342 = 138%

$\underline{MZ = 0 + 0 + (111) + (-176) + (-293) + (-1194) = -1552}$

Allowable = 125Dc = 125(18.737) = 2342

1552/2342 = 66%

$$2\sqrt{(598)^2 + (2304)^2 + (1039)^2} \quad + \quad \sqrt{(488)^2 + (3236)^2 + (1552)^2}$$

$= 8816$

Allowable = 250Dc = 250(18.737) = 4684

8816/4684 = 188%

TURBO-MACHINERY ANALYSIS

☐ NEMA ☒ API-617

PAGE 1

36.	D	Nominal diameter
0.	ΔX	X-coordinate
0.	ΔY	Y-coordinate
0.	ΔZ	Z-coordinate
0.	FX	X-nozzle force
1697.	FY	Y-nozzle force
-815.	FZ	Z-nozzle force
-2938.	MX	X-nozzle moment
0.	MY	Y-nozzle moment
0.	MZ	Z-nozzle moment
8586.	3F+M	Applied 3F+M
16033.	ALL	Allowable 3F+M
54.	%	% applied/allowable
0.	TMX	X-induced moment
0.	TMY	Y-induced moment
0.	TMZ	Z-induced moment
8.	D	Nominal diameter
3.75	ΔX	X-coordinate
-1.4583	ΔY	Y-coordinate
-4.2188	ΔZ	Z-coordinate
-10.	FX	X-nozzle force
-43.	FY	Y-nozzle force
-22.	FZ	Z-nozzle force
129.	MX	X-nozzle moment
-1517.	MY	Y-nozzle moment
111.	MZ	Z-nozzle moment
1674.	3F+M	Applied 3F+M
7400.	ALL	Allowable 3F+M
23.	%	% applied/allowable
-149.	TMX	X-induced moment
125.	TMY	Y-induced moment
-176.	TMZ	Z-induced moment

10.	D
2.0833	ΔX
-4.3333	ΔY
-2.5	ΔZ
-588.	FX
650.	FY
-202.	FZ
946.	MX
2737.	MY
-293.	MZ
5609.	3F+M
8017.	ALL
70.	%
2500.	TMX
1891.	TMY
-1194.	TMZ

Example 2

TURBO-MACHINERY ANALYSIS

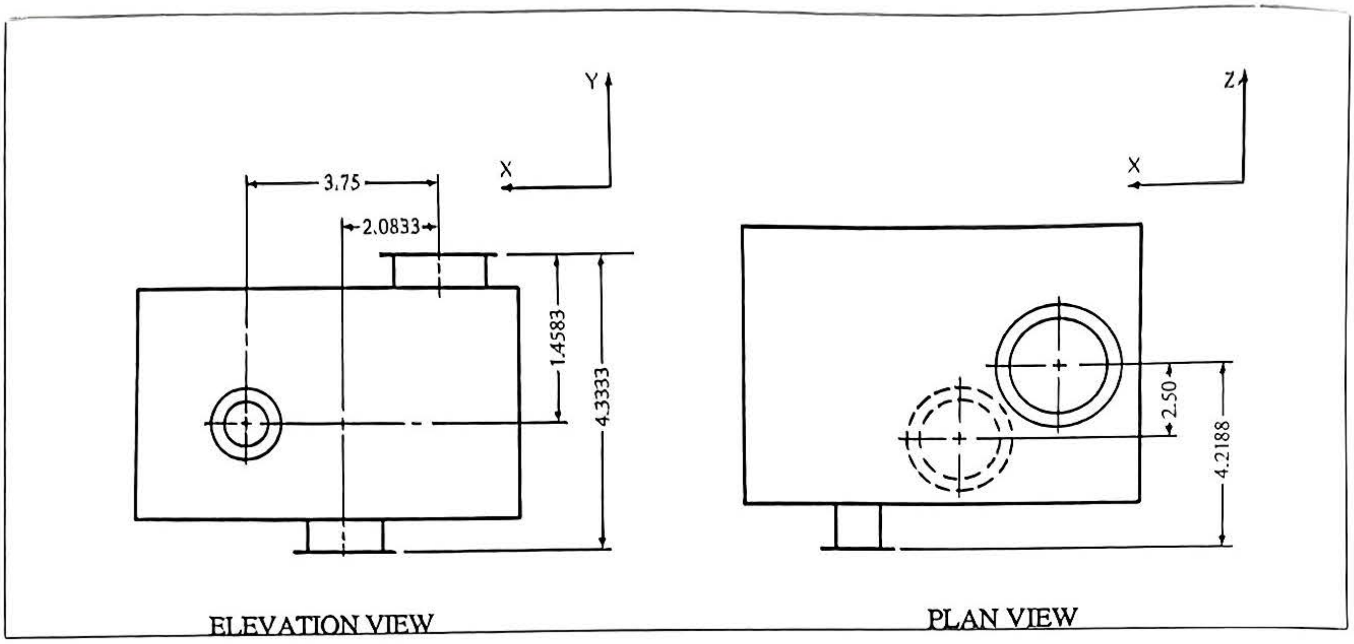
☐ NEMA ☒ API-617

PAGE 2

-598.	FX	Summed X-Forces at the reference nozzle
1733.	ALL	Allowable FX
35.	%	% applied/allowable
2304.	FY	Summed Y-forces at the reference nozzle
4333.	ALL	Allowable FY
53.	%	% applied/allowable
-1039.	FZ	Summed Z-forces at the reference nozzle
3466.	ALL	Allowable FZ
30.	%	% applied/allowable
488.	MX	Summed X-moments at the reference nozzle
8666.	ALL	Allowable MX
6.	%	% applied/allowable
3236.	MY	Summed Y-moments at the reference nozzle
4333.	ALL	Allowable MY
75.	%	% applied/allowable
-1552.	MZ	Summed Z-moments at the reference nozzle
4333.	ALL	Allowable MZ
36.	%	% applied/allowable
8816.	2F+M	Applied 2F+M from the summed values listed above
8666.	ALL	Allowable 2F+M
102.	%	% applied/allowable

Sample Problem

Program: TI-59-12



Step	Input	Key Stroke	Display	Printer		Comments
1		E	0.			Initialize program. Stores alpha labels in R01 through R10.
2	36	A	36.	36.	D	Stores D in R01. Prints data.
3	0	A	0.	0.	ΔX	Stores X in R02. Prints data.
4	0	A	0.	0.	ΔY	Stores Y in R03. Prints data.
5	0	A	0.	0.	ΔZ	Stores Z in R04. Prints data.
6	0	A	0.	0.	FX	Stores FX in R05. Prints data.
7	1697	A	1697.	1697.	FY	Stores FY in R06. Prints data.
8	-815	A	-815.	-815.	FZ	Stores FZ in R07. Prints data.
9	-2938	A	-2938.	-2938.	MX	Stores MX in R08. Prints data.
10	0	A	0.	0.	MY	Stores MY in R09. Prints data.
11	0	A	0.	0.	MZ	Stores MZ in R10. Prints data.
12		B	0.	8586. 8667. 99. 0. 0. 0.	3F+M ALL % TMX TMY TMZ	Calculates De for the input value of D. From De, the allowable for 3F+M is calculated and stored in R11. Calculates 3F+M and stores it in R13. Prints the 3F+M value, the allowable and the percent -

Step	Input	Key Stroke	Display	Printer		Comments
						age of allowable. Then the program transfers all the applied forces and moments to the reference nozzle registers, R14 through R19. The moments that are transferred to the reference nozzle because of the applied forces acting through the coordinate distances are calculated, printed, and summed into the refer - ence nozzle registers, R17 through R19. The program then resets the alpha codes and stops.
13	8	A	8.	8.	D	
14	3.75	A	3.75	3.75	ΔX	
15	-1.4583	A	-1.4583	-1.4583	ΔY	
16	-4.2188	A	-4.2188	-4.2188	ΔZ	
17	-10	A	-10.	-10.	FX	Exactly the same routine as in Steps 2 through 12.
18	-43	A	-43.	-43.	FY	
19	-22	A	-22.	-22.	FZ	
20	129	A	129.	129.	MX	
21	-1517	A	-1517.	-1517.	MY	
22	111	A	111.	111.	MZ	
23		B	0.			
				1674.	3F+M	
				4000.	ALL	
				42.	%	
				-149.	TMX	
				125.	TMY	
				-176.	TMZ	
24	10	A	10.	10.	D	
25	2.0833	A	2.0833	2.0833	ΔX	
26	-4.3333	A	-4.3333	-4.3333	ΔY	Exactly the same routine as in Steps 2 through 12.
27	-2.5	A	-2.5	-2.5	ΔZ	
28	-588	A	-588.	-588.	FX	
29	650	A	650.	650.	FY	
30	-202	A	-202.	-202.	FZ	
31	946	A	946.	946.	MX	
32	2737	A	2737.	2737.	MY	
33	-293	A	-293.	-293.	MZ	
34		B	0.			
				5609.	3F+M	
				4333.	ALL	
				129.	%	
				2500.	TMX	
				1891.	TMY	
				-1194.	TMZ	

Step	Input	Key Stroke	Display	Printer		Comments
35	D			-598.	FX	Calculates and stores the casing allowables using a calculated value of Dc. The Allowables are stored in R21 through R26.
				937.	ALL	
				64.	%	
				2304.	FY	The accumulated forces and moments at the reference nozzle are printed along with the respective allowables and the percentage of the allowable.
				2342.	ALL	
				98.	%	
				-1039.	FZ	Finally, the 2F+M value is calculated and stored in R29. The 2F+M value is then printed along with its allowable, and the percentage of the allowable.
				1874.	ALL	
				55.	%	
				488.	MX	
				4684.	ALL	
				10.	%	
				3236.	MY	
				2342.	ALL	
				138.	%	
				-1552.	MZ	
				2342.	ALL	
				66.	%	
				8816.	2F+M	
				4684.	ALL	
				188.	%	

Coding Form

Program Number TI-59-12 **Title** Turbo-machinery Loading Analysis

Loc	Code	Key	Comments
000	10	E'	Initialize.
001	76	LBL	
002	15	E	
003	47	CMS	
004	81	RST	
005	76	LBL	Input routine.
006	11	A	
007	69	OP	
008	20	20	
009	63	EX*	
010	00	00	
011	69	OP	
012	04	04	
013	73	RC*	
014	00	00	
015	69	OP	
016	06	06	
017	91	R/S	
018	76	LBL	API-617 factor.
019	16	A'	
020	65	×	
021	01	1	
022	93	.	
023	08	8	
024	05	5	
025	92	RTN	
026	76	LBL	Print routine for applied values, the allowables, and the percent difference.
027	19	D'	
028	43	RCL	
029	20	20	
030	69	OP	
031	04	04	
032	73	RC*	
033	27	27	
034	69	OP	
035	06	06	
036	43	RCL	
037	30	30	
038	69	OP	
039	04	04	
040	73	RC*	
041	28	28	
042	69	OP	
043	06	06	
044	06	6	
045	01	1	
046	69	OP	
047	04	04	
048	73	RC*	
049	27	27	
050	55	÷	
051	73	RC*	
052	28	28	
053	65	×	
054	01	1	
055	00	0	
056	00	0	
057	95	=	
058	50	IxI	
059	69	OP	
060	06	06	
061	98	ADV	
062	01	1	
063	44	SUM	
064	20	20	
065	44	SUM	
066	27	27	
067	44	SUM	
068	28	28	
069	97	DSZ	
070	00	00	
071	19	D'	
072	92	RTN	
073	76	LBL	Print routine for transferred moments.
074	17	B'	
075	32	X:T	
076	43	RCL	
077	00	00	
078	69	OP	
079	04	04	
080	32	X:T	
081	69	OP	
082	06	06	
083	69	OP	
084	20	20	
085	92	RTN	
086	76	LBL	Individual nozzle routine.
087	12	B	
088	98	ADV	
089	08	8	
090	93	.	
091	01	1	
092	32	X:T	
093	43	RCL	
094	01	01	
095	22	INV	
096	77	GE	
097	24	CE	Determines De.
098	85	+	
099	01	1	
100	06	6	
101	54	)	
102	55	÷	
103	03	3	
104	95	=	
105	76	LBL	
106	24	CE	
107	65	×	Calculates 3F + M allowable.
108	05	5	
109	00	0	
110	00	0	
111	22	INV	
112	87	IFF	
113	01	01	
114	25	CLR	
115	16	A'	Adjusts for API-617.
116	76	LBL	
117	25	CLR	
118	95	=	
119	42	STO	
120	11	11	
121	43	RCL	
122	01	01	
123	33	X²	
124	44	SUM	
125	12	12	
126	43	RCL	
127	05	05	
128	33	X²	
129	85	+	
130	43	RCL	
131	06	06	
132	33	X²	
133	85	+	Calculates 3F + M.
134	43	RCL	
135	07	07	
136	33	X²	
137	54	)	
138	34	√x	
139	65	×	
140	03	3	
141	85	+	
142	53	(	
143	43	RCL	
144	08	08	
145	33	X²	
146	85	+	
147	43	RCL	
148	09	09	
149	33	X²	
150	85	+	
151	43	RCL	
152	10	10	
153	33	X²	
154	54	)	
155	34	√x	
156	95	=	
157	42	STO	
158	13	13	
159	58	FIX	Prints 3F + M and allowable using print routine D'.
160	00	00	
161	04	4	
162	02	2	
163	01	1	
164	04	4	
165	07	7	
166	03	3	
167	00	0	
168	42	STO	
169	20	20	
170	01	1	
171	03	3	
172	42	STO	
173	27	27	
174	01	1	
175	01	1	
176	42	STO	
177	28	28	
178	01	1	
179	42	STO	

Loc	Code	Key	Comments
180	00	00	
181	19	D'	
182	43	RCL	
183	05	05	
184	44	SUM	
185	14	14	
186	43	RCL	
187	06	06	
188	44	SUM	
189	15	15	
190	43	RCL	Transfers individual nozzle loads to the reference nozzle.
191	07	07	
192	44	SUM	
193	16	16	
194	43	RCL	
195	08	08	
196	44	SUM	
197	17	17	
198	43	RCL	
199	09	09	
200	44	SUM	
201	18	18	
202	43	RCL	
203	10	10	
204	44	SUM	
205	19	19	
206	03	3	
207	07	7	
208	03	3	
209	00	0	
210	04	4	
211	04	4	
212	42	STO	
213	00	00	
214	43	RCL	
215	07	07	
216	65	×	Calculates MX due to nozzle forces.
217	43	RCL	
218	03	03	
219	75	-	
220	43	RCL	
221	06	06	
222	65	×	
223	43	RCL	
224	04	04	Uses print routine B'.
225	95	=	
226	44	SUM	
227	17	17	
228	17	B'	
229	43	RCL	
230	05	05	
231	65	×	
232	43	RCL	Calculates MY due to nozzle forces.
233	04	04	
234	75	-	
235	43	RCL	
236	07	07	
237	65	×	
238	43	RCL	
239	02	02	

Loc	Code	Key	Comments
240	95	=	Uses print routine B'.
241	44	SUM	
242	18	18	
243	17	B'	
244	43	RCL	
245	06	06	
246	65	×	
247	43	RCL	
248	02	02	Calculates MZ due to nozzle forces.
249	75	-	
250	43	RCL	
251	05	05	
252	65	×	
253	43	RCL	
254	03	03	Uses print routine B'.
255	95	=	
256	44	SUM	
257	19	19	
258	17	B'	
259	10	E'	Go to E'.
260	76	LBL	Casing loading analysis.
261	14	D	
262	58	FIX	
263	00	00	
264	05	5	
265	00	0	Store Dc multipliers in allowable registers.
266	42	STO	
267	21	21	
268	01	1	
269	00	0	
270	00	0	
271	42	STO	
272	23	23	
273	01	1	
274	02	2	
275	05	5	
276	42	STO	
277	22	22	
278	42	STO	
279	25	25	
280	42	STO	
281	26	26	
282	02	2	
283	05	5	
284	00	0	
285	42	STO	
286	24	24	
287	09	9	
288	32	X⇌T	Calculate Dc.
289	43	RCL	
290	12	12	
291	34	√X	
292	22	INV	
293	77	GE	
294	23	LNX	
295	85	+	
296	01	1	
297	08	8	
298	54	)	
299	55	÷	

Loc	Code	Key	Comments
300	03	3	
301	76	LBL	
302	23	LNX	
303	22	INV	
304	87	IFF	Adjust for API-617.
305	01	01	
306	28	LOG	
307	16	A'	
308	76	LBL	
309	23	LOG	
310	95	=	
311	49	PRD	
312	21	21	Calculate casing allowables.
313	49	PRD	
314	22	22	
315	49	PRD	
316	23	23	
317	49	PRD	
318	24	24	
319	49	PRD	
320	25	25	
321	49	PRD	
322	26	26	
323	03	3	Print summed forces at reference nozzle and the allowables using print routine D'.
324	42	STO	
325	00	00	
326	01	1	
327	04	4	
328	42	STO	
329	27	27	
330	02	2	
331	01	1	
332	42	STO	
333	28	28	
334	02	2	
335	01	1	
336	04	4	
337	04	4	
338	42	STO	
339	20	20	
340	19	D'	
341	03	3	Print summed moments at reference nozzle and allowables using D'.
342	00	0	
343	04	4	
344	04	4	
345	42	STO	
346	20	20	
347	03	3	
348	42	STO	
349	00	00	
350	19	D'	
351	98	ADV	
352	43	RCL	
353	14	14	Calculate 2F + M.
354	33	X²	
355	85	+	
356	43	RCL	
357	15	15	
358	33	X²	
359	85	+	

Loc	Code	Key	Comments
360	43	RCL	
361	16	16	
362	33	X^2	
363	54	)	
364	34	ΓX	
365	65	×	
366	02	2	
367	85	+	
368	53	(	
369	43	RCL	
370	17	17	
371	33	X^2	
372	85	+	
373	43	RCL	
374	18	18	
375	33	X^2	
376	85	+	
377	43	RCL	
378	19	19	
379	33	X^2	
380	54	)	
381	34	ΓX	
382	95	=	
383	42	STO	
384	29	29	
385	02	2	Print 2F + M, the allowable and the percent difference using print routine D′.
386	09	9	
387	42	STO	
388	27	27	
389	02	2	
390	04	4	
391	42	STO	
392	28	28	
393	03	3	
394	02	2	
395	01	1	
396	04	4	
397	07	7	
398	03	3	
399	00	0	
400	42	STO	
401	20	20	
402	01	1	
403	42	STO	
404	00	00	
405	19	D'	
406	98	ADV	
407	25	CLR	
408	91	R/S	
409	76	LBL	Set API-617 flag.
410	13	C	
411	86	STF	
412	01	01	
413	61	GTO	Go to B.
414	12	B	
415	76	LBL	
416	10	E'	Set alpha labels for input routine.
417	22	INV	
418	58	FIX	
419	98	ADV	

Loc	Code	Key	Comments
420	01	1	
421	03	3	
422	02	2	
423	07	7	
424	02	2	
425	07	7	
426	42	STO	
427	30	30	
428	01	1	
429	06	6	
430	42	STO	
431	01	01	
432	07	7	
433	05	5	
434	04	4	
435	04	4	
436	42	STO	
437	02	02	
438	42	STO	
439	03	03	
440	42	STO	
441	04	04	
442	02	2	
443	01	1	
444	04	4	
445	04	4	
446	42	STO	
447	05	05	
448	42	STO	
449	06	06	
450	42	STO	
451	07	07	
452	03	3	
453	00	0	
454	04	4	
455	04	4	
456	42	STO	
457	08	08	
458	42	STO	
459	09	09	
460	42	STO	
461	10	10	
462	01	1	
463	44	SUM	
464	03	03	
465	44	SUM	
466	06	06	
467	44	SUM	
468	09	09	
469	02	2	
470	44	SUM	
471	04	04	
472	44	SUM	
473	07	07	
474	44	SUM	
475	10	10	
476	25	CLR	
477	42	STO	
478	00	00	
479	91	R/S	

Program HP-41CV-12: Turbo-machinery Loading Analysis Per NEMA SM-23 and API-617

Introduction:

HP-41CV-12 performs the individual nozzle loading analysis and the transformed casing loading analysis for steam driven, single, and multistage turbines, set out in National Electrical Machinery Association publication SM-23. The program also performs the analysis for centrifugal compressors from API-617. HP-41CV-12 performs the load transformations, calculates the allowables, and compares the applied loading with the allowables.

Nomenclature:

The user will input the coordinates of the individual nozzles, the applied loads, and the nominal diameter of the nozzle. The following terms will be used:

- ND: Nozzle nominal diameter (in)
- DLT X: Distance from the reference nozzle to the individual nozzle along the X-axis (ft)
- DLT Y: Same as above for the Y-axis (ft)
- DLT Z: Same as above for the Z-axis (ft)
- FX: Force applied to the individual nozzle in the X-direction (lb)
- FY: Same as above for the Y-direction (lb)
- FZ: Same as above for the Z-direction (lb)
- MX: Moment about the X-axis, applied to the individual nozzle (ft-lb)
- MY: Moment about the Y-axis, applied to the individual nozzle (ft-lb)
- MZ: Moment about the Z-axis, applied to the individual nozzle (ft-lb)
- TMX: Transferred moment due to FY and FZ (ft-lb)
- TMY: Transferred moment due to FX and FZ (ft-lb)
- TMZ: Transferred moment due to FX and FY (ft-lb)

The following user-keys execute the program:

- A: Error recovery key
- B: Execute individual nozzle analysis (NEMA)
- C: Execute individual nozzle analysis (API-617)
- D: Execute casing analysis (NEMA and API-617)
- E: Initialize program and begin input sequence
- R/S: Used with E for data input

Method:

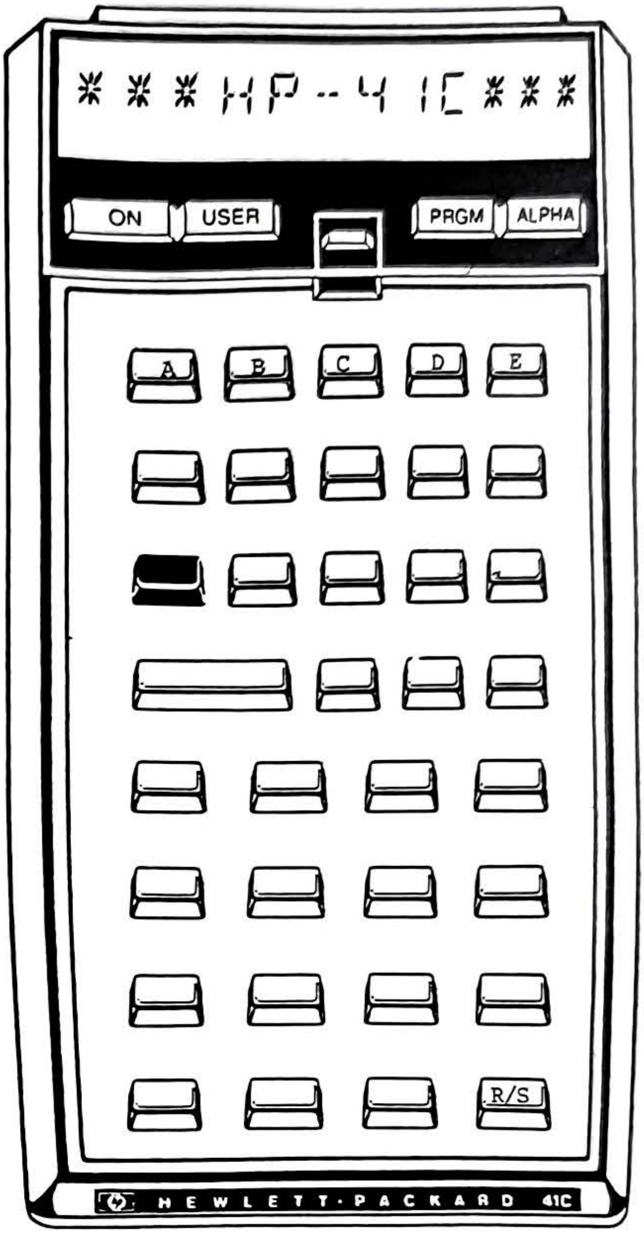
HP-41CV-12 calculates the "3F+M" value for the individual nozzle loading, determines the allowable, and expresses the difference between the two values as a percentage of the allowable. The nozzle loads are then transformed to the reference nozzle. The "force-induced" moments are printed for the user's information. (Force-induced moments are moments about the reference nozzle due to the forces applied to the individual nozzles.) The final execution of the program prints the accumulated forces and moments at the reference nozzle along with their respective allowables. As before, the relationship between applied loads and allowables is expressed as a percentage of the allowable. The "2F+M" value is calculated and compared with its allowable.

Limitations:

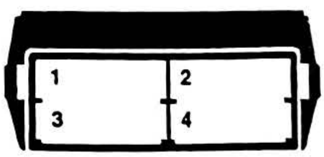
The program accepts an unlimited number of individual nozzles. All input must be done in English units. If an error in input is made, there is an error recovery key, A. See user instructions for its use.

Keyboard Card Labeling

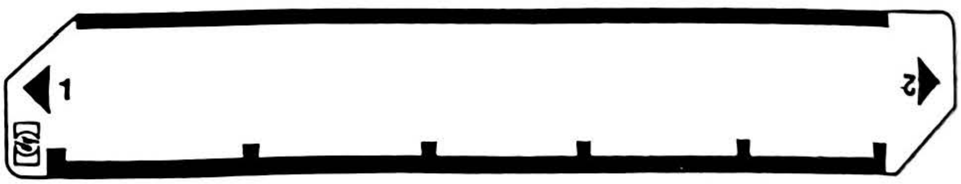
KEYBOARD



SYSTEM CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-12 **Title** Turbo-machinery Loading Analysis

Step	Instructions	Input	Keystroke	Display
1	Initialize program.		E	ND=
2	Input ND.	ND	R/S	DLT X=
3	Input DLT X.	DLT X	R/S	DLT Y=
4	Input DLT Y.	DLT Y	R/S	DLT Z=
5	Input DLT Z.	DLT Z	R/S	FX=
6	Input FX.	FX	R/S	FY=
7	Input FY.	FY	R/S	FZ=
8	Input FZ.	FZ	R/S	MX=
9	Input MX.	MX	R/S	MY=
10	Input MY.	MY	R/S	MZ=
11	Input MZ.	MZ	R/S	B OR C
12	Choose the analaysis, NEMA SM-23 or API-617.		B or C	
				DATA OUTPUT
	Repeat Steps 2 through 12 for all nozzles on the machine. After the program has acted on the last nozzle input:			
13	Perform casing analysis.		D	DATA OUTPUT

If an error occurs in input, press A and repeat Steps 2 through 12. The program will prompt again for ND.

Registers, Flags, Assignments

Program Number HP-41CV-12 **Title** Turbo-machinery Loading Analysis

DATA REGISTERS

00	DSE
01	ND
02	ΔX
03	ΔY
04	ΔZ
05	FX
06	FY
07	FZ
08	MX
09	MY
10	MZ
11	3F + M Allowable
12	ΣND
13	3F + M
14	ΣFX
15	ΣFY
16	ΣFZ
17	ΣMX
18	ΣMY
19	ΣMZ
20	
21	FX
22	FY
23	FZ ALLOWABLES
24	MX
25	MY
26	MZ
27	IND
28	IND
29	IND/2F + M
30	
31	"ND="
32	"DLT X="
33	"DLT Y="
34	"DLT Z="
35	"FX="
36	"FY="
37	"FZ="
38	"MX="
39	"MY="
40	"MZ="
41	
42	
43	
44	
45	
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates
1	C	API-617 analysis	NEMA analysis

ASSIGNMENTS

Label	Key	Function	Key
AC	11 (A)		
BB	12 (B)		
CC	13 (C)		
DD	14 (D)		
NEMA	15 (E)		

Analysis according to NEMA SM23

```
ND= 36.000
DLT  X= 0.000
DLT  Y= 0.000
DLT  Z= 0.000
FX= 0.000
FY= 1,697.000
FZ=-815.000
MX=-2,938.000
MY= 0.000
MZ= 0.000

3F+M=8,586.
ALLOW=8,667.
=99.%

TMX:TMY:TMZ
0.:0.:0.


ND= 8.000
DLT  X= 3.750
DLT  Y=-1.458
DLT  Z=-4.219
FX=-10.000
FY=-43.000
FZ=-22.000
MX= 129.000
MY=-1,517.000
MZ= 111.000

3F+M=1,674.
ALLOW=4,000.
=42.%

TMX:TMY:TMZ
-149.:125.:-176.


ND= 10.000
DLT  X= 2.083
DLT  Y=-4.333
DLT  Z=-2.500
FX=-588.000
FY= 650.000
FZ=-202.000
MX= 946.000
MY= 2,737.000
MZ=-293.000

3F+M=5,609.
ALLOW=4,333.
=129.%

TMX:TMY:TMZ
2,500.:1,891.:-1,194.
```

```
FX=-598.
ALLOW=937.
=64.%

FY=2,304.
ALLOW=2,342.
=98.%

FZ=-1,039.
ALLOW=1,874.
=55.%

MX=488.
ALLOW=4,684.
=10.%

MY=3,236.
ALLOW=2,342.
=138.%

MZ=-1,552.
ALLOW=2,342.
=66.%


2F+M=8,816.
ALLOW=4,684.
=188.%
```

Nozzle 1

FX = 0	MX = −2938	$\Delta X = 0$
FY = 1697	MY = 0	$\Delta Y = 0$
FZ = −815	MZ = 0	$\Delta Z = 0$

De = (36 + 16)/3 = 17.333 : Allowable = 500(17.333) = 8667

$$3\sqrt{(0)^2 + (1697)^2 + (815)^2} \quad + \quad \sqrt{(2938)^2 + (0)^2 + (0)^2} = 8586$$

8586/8667 = 99%

NO MOMENTS TRANSFERRED

Nozzle 2

FX = −10	MX = 129	$\Delta X = 3.75$
FY = −43	MY = −1517	$\Delta Y = -1.4583$
FZ = −22	MZ = 111	$\Delta Z = -4.2188$

De = 8 : Allowable = 500(8) = 4000

$$3\sqrt{(10)^2 + (43)^2 + (22)^2} \quad + \quad \sqrt{(129)^2 + (1517)^2 + (111)^2} = 1674$$

1674/4000 = 42%

TMX = (−22)(−1.4583) − (−43)(−4.2188) = −149 ft-lb
TMY = (−10)(−4.2188) − (−22)(3.75) = 125 ft-lb
TMZ = (−43)(3.75) − (−10)(−1.4583) = −176 ft-lb

Nozzle 3

FX = −588	MX = 946	$\Delta X = 2.0833$
FY = 650	MY = 2737	$\Delta Y = -4.333$
FZ = −202	MZ = −293	$\Delta Z = -2.5$

De = (10 + 16)/3 = 8.667 : Allowable = 500(8.667) = 4333

$$3\sqrt{(588)^2 + (650)^2 + (202)^2} \quad + \quad \sqrt{(946)^2 + (2737)^2 + (293)^2} = 5609$$

5609/4333 = 129%

TMX = (−202)(−4.3333) − (650)(−2.5) = 2500 ft-lb
TMY = (−588)(−2.5) − (−202)(2.0833) = 1891 ft-lb
TMZ = (650)(2.0833) − (−588)(−4.3333) = −1194 ft-lb

$$Dc = \left(\sqrt{(36)^2 + (8)^2 + (10)^2} + 18\right)/3 = 18.737$$

$\underline{FX = 0 + (-10) + (-588) = -598}$

Allowable = 50Dc = 50(18.737) = 937

598/937 = 64%

$\underline{FY = (1697) + (-43) + (650) = 2304}$

Allowable = 125Dc = 125(18.737) = 2342

2304/2342 = 98%

$\underline{FZ = (-815) + (-22) + (-202) = -1039}$

Allowable = 100Dc = 100(18.737) = 1874

1039/1874 = 55%

$\underline{MX = (-2938) + 0 + (129) + (-149) + (946) + (2500) = 488}$

Allowable = 250Dc = 250(18.737) = 4684

488/4684 = 10%

$\underline{MY = 0 + 0 + (-1517) + (125) + (2737) + (1891) = 3236}$

Allowable = 125Dc = 125(18.737) = 2342

3236/2342 = 138%

$\underline{MZ = 0 + 0 + (111) + (-176) + (-293) + (-1194) = -1552}$

Allowable = 125Dc = 125(18.737) = 2342

1552/2342 = 66%

$$2\sqrt{(598)^2 + (2304)^2 + (1039)^2} \quad + \quad \sqrt{(488)^2 + (3236)^2 + (1552)^2}$$

$$= 8816$$

Allowable = 250Dc = 250(18.737) = 4684

8816/4684 = 188%

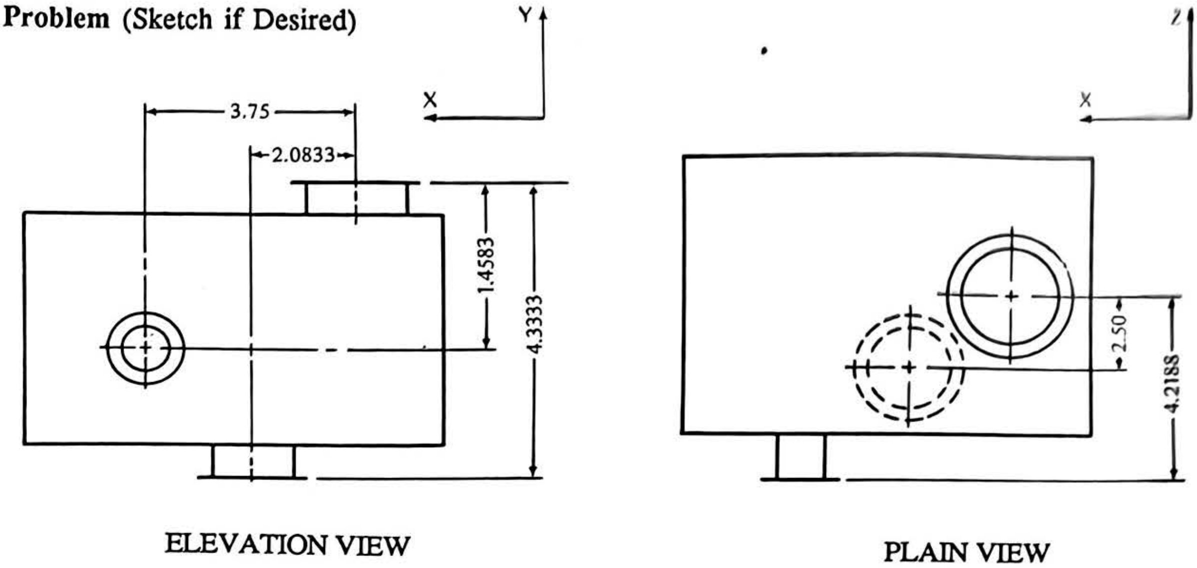
```
ND= 36.000
DLT  X= 0.000
DLT  Y= 0.000
DLT  Z= 0.000
FX= 0.000
FY= 1,697.000
FZ=-815.000
MX=-2,938.000
MY= 0.000
MZ= 0.000

3F+M=8,586.
ALLOW=16,033.
=54.%

TMX : TMY : TMZ
0.:0.:0.


ND= 8.000
DLT  X= 3.750
DLT  Y=-1.458
DLT  Z=-4.219
FX=-10.000
FY=-43.000
FZ=-22.000
MX= 129.000
MY=-1,517.000
MZ= 111.000

3F+M=1,674.
ALLOW=7,400.
=23.%

TMX : TMY : TMZ
-149.:125.:-176.


ND= 10.000
DLT  X= 2.083
DLT  Y=-4.333
DLT  Z=-2.500
FX=-588.000
FY= 650.000
FZ=-202.000
MX= 946.000
MY= 2,737.000
MZ=-293.000

3F+M=5,609.
ALLOW=8,017.
=70.%

TMX : TMY : TMZ
2,500.:1,891.:-1,194.
```

```
FX=-598.
ALLOW=1,733.
=35.%

FY=2,304.
ALLOW=4,333.
=53.%

FZ=-1,039.
ALLOW=3,466.
=30.%

MX=488.
ALLOW=8,666.
=6.%

MY=3,236.
ALLOW=4,333.
=75.%

MZ=-1,552.
ALLOW=4,333.
=36.%


2F+M=8,816.
ALLOW=8,666.
=102.%
```

Sample Problem

Program: HP-41CV-12 Title Turbo-machinery Loading Analysis

Sample Problem (Sketch if Desired)



Input	Function	Display	Comments
	E	ND=	
36	R/S	DLT X=	The program will analyze each set of loads as it is input. The first analysis is the individual nozzle analysis that determines the 3F+M value and the corresponding allowable.
0.0	R/S	DLT Y=	
0.0	R/S	DLT Z=	
0.0	R/S	FX=	
0	R/S	FY=	
1697	R/S	FZ=	
-815	R/S	MX=	
-2938	R/S	MY=	
0	R/S	MZ=	
0	R/S	B OR C	By choosing key C the analyst has told the program to calculate the allowables per API-617. If key B is chosen, the allowables will be those for NEMA SM-23.
	C		
		3F+M=8586.	
		ALLOW= 16,033.	
		=54.%	
		TMX:TMY:TMZ	
		0.:0.:0.	
		ND=	TMX refers to the moment in the X-direction that is transferred to the reference nozzle. The value of the moment is the result of the FY and FZ forces applied through the Y and Z distances to the reference nozzle. They are *not* the total transferred moment.
8	R/S	DLT X=	
3.75	R/S	DLT Y=	
-1.4583	R/S	DLT Z=	

Input	Function	Display	Comments
-4.2188	R/S	FX=	
-10	R/S	FY=	
-43	R/S	FZ=	
-22	R/S	MX=	
129	R/S	MY=	
-1517	R/S	MZ=	
111	R/S	B OR C	
	C		
		3F+M=1674. ALLOW=7,400. =23.%	
		TMX:TMY:TMZ -149.:125.:176.	
		ND=	
10	R/S	DLT X=	
2.0833	R/S	DLT Y=	
-4.3333	R/S	DLT Z=	
-2.5	R/S	FX=	
-588	R/S	FY=	
650	R/S	FZ=	
-202	R/S	MX=	
946	R/S	MY=	
2737	R/S	MZ=	
-293	R/S	B OR C	
	C		
		3F+M=5609. ALLOW=8017. =70.%	
		TMX:TMY:TMZ 2,500.:1,891.: -1,194.	
		ND=	This begins the casing analysis. Each accumulated force and moment is listed against its allowable. Finally, the 2F+M value is printed and compared with its allowable.
	D		
		FX=-598. ALLOW=1,733. =35.%	
		FY=2,304. ALLOW=4,333. =53.%	
		FZ=-1,039. ALLOW=3,466. =30.%	

Input	Function	Display	Comments
		MX=488. ALLOW=8,666. =6.%	
		MY=3,326. ALLOW=4,333. =75.%	
		MZ=1,522. ALLOW=4,333. =36.%	
		2F+M=8,816. ALLOW=8,666. =102.%	

Program Number HP-41CV-12 Title Turbo-machinery Loading Analysis

Step/Line Key Entry	Key Code	Comments
01♦LBL "NEMA"		Initialize program.
02 CLRG		
03 CLA		
04 CF 01		
05 "HD="		
06 ASTO 31		
07 "DLT X="		
08 ASTO 32		
09 "DLT Y="		
10 ASTO 33		
11 "DLT Z="		
12 ASTO 34		
13 "FX="		
14 ASTO 35		
15 "FY="		
16 ASTO 36		
17 "FZ="		
18 ASTO 37		
19 "MX="		
20 ASTO 38		
21 "MY="		
22 ASTO 39		
23 "MZ="		
24 ASTO 40		
25♦LBL "AA"		Set up input routine.
26 CLA		
27 1.01		
28 STO 00		
29 31		
30 STO 27		
31 FIX 3		
32♦LBL "AB"		Input routine.
33 ARCL IND 27		
34 PROMPT		
35 SF 12		
36 ACA		
37 CF 12		
38 ACX		
39 STO IND 00		
40 PRBUF		
41 CLA		
42 1		
43 ST+ 27		
44 CLX		
45 ISG 00		
46 GTO "AB"		
47 "B OR C"		Prompt for NEMA or API-617.
48 PROMPT		
49♦LBL "CC"		Set API-617 flag.
50 SF 01		
51♦LBL "BB"		Calculate 3F + M allowable (De)(500).
52 ADV		
53 8		
54 RCL 01		
55 X<Y?		
56 GTO A		
57 16		
58 +		
59 3		
60 /		
61♦LBL A		
62 500		
63 *		
64 FC? 01		
65 GTO B		
66 1.85		Adjust for API-617.
67 *		
68♦LBL B		
69 STO 11		
70 RCL 01		Calculate 3F + M.
71 X↑2		
72 ST+ 12		
73 RCL 05		
74 X↑2		
75 RCL 06		
76 X↑2		
77 RCL 07		
78 X↑2		
79 +		
80 +		
81 SQRT		
82 3		
83 *		
84 RCL 08		
85 X↑2		
86 RCL 09		
87 X↑2		
88 RCL 10		
89 X↑2		
90 +		
91 +		
92 SQRT		
93 +		
94 STO 13		
95 FIX 0		Print 3F + M, allowable and % difference.
96 13		
97 STO 27		
98 11		
99 STO 28		
100 "3F+M="		
101 XEQ D		
102 RCL 05		Sum nozzle loads into reference nozzle registers.
103 ST+ 14		
104 RCL 06		
105 ST+ 15		
106 RCL 07		
107 ST+ 16		
108 RCL 08		
109 ST+ 17		
110 RCL 09		
111 ST+ 18		
112 RCL 10		
113 ST+ 19		
114 RCL 07		Calculate transferred MX sum into reference nozzle registers.
115 RCL 03		
116 *		
117 RCL 06		
118 RCL 04		
119 *		
120 -		
121 ST+ 17		
122 STO 27		
123 RCL 05		Calculate MY same as above.
124 RCL 04		
125 *		
126 RCL 07		
127 RCL 02		
128 *		
129 -		
130 ST+ 18		
131 STO 28		
132 RCL 06		Calculate MZ same as above.
133 RCL 02		
134 *		
135 RCL 05		
136 RCL 03		
137 *		
138 -		
139 ST+ 19		
140 STO 29		
141 SF 12		Print transferred MX, MY, and MZ (force-induced moments).
142 "TMX:TMY: TMZ"		
143 PRA		
144 CLA		
145 CF 12		
146 ARCL 27		

Input	Function	Display	Comments
		MX=488. ALLOW=8,666. =6.%	
		MY=3,326. ALLOW=4,333. =75.%	
		MZ=1,522. ALLOW=4,333. =36.%	
		2F+M=8,816. ALLOW=8,666. =102.%	

Coding Form

Program Number HP-41CV-12 Title Turbo-machinery Loading Analysis

Step/Line Key Entry	Key Code	Comments
01♦LBL "NEMA"		Initialize program.
02 CLRG		
03 CLA		
04 CF 01		
05 "ND="		
06 ASTO 31		
07 "DLT X="		
08 ASTO 32		
09 "DLT Y="		
10 ASTO 33		
11 "DLT Z="		
12 ASTO 34		
13 "FX="		
14 ASTO 35		
15 "FY="		
16 ASTO 36		
17 "FZ="		
18 ASTO 37		
19 "MX="		
20 ASTO 38		
21 "MY="		
22 ASTO 39		
23 "MZ="		
24 ASTO 40		
25♦LBL "AA"		Set up input routine.
26 CLA		
27 1.01		
28 STO 00		
29 31		
30 STO 27		
31 FIX 3		
32♦LBL "AB"		Input routine.
33 ARCL IND 27		
34 PROMPT		
35 SF 12		
36 ACA		
37 CF 12		
38 ACX		
39 STO IND 00		
40 PRBUF		
41 CLA		
42 1		
43 ST+ 27		
44 CLX		
45 ISG 00		
46 GTO "AB"		
47 "B OR C"		Prompt for NEMA or API-617.
48 PROMPT		
49♦LBL "CC"		Set API-617 flag.

Step/Line Key Entry	Key Code	Comments
50 SF 01		
51♦LBL "BB"		Calculate 3F + M allowable (De)(500).
52 ADV		
53 8		
54 RCL 01		
55 X<Y?		
56 GTO A		
57 16		
58 +		
59 3		
60 /		
61♦LBL A		
62 500		
63 *		
64 FC? 01		
65 GTO B		
66 1.85		Adjust for API-617.
67 *		
68♦LBL B		
69 STO 11		
70 RCL 01		Calculate 3F + M.
71 X↑2		
72 ST+ 12		
73 RCL 05		
74 X↑2		
75 RCL 06		
76 X↑2		
77 RCL 07		
78 X↑2		
79 +		
80 +		
81 SQRT		
82 3		
83 *		
84 RCL 08		
85 X↑2		
86 RCL 09		
87 X↑2		
88 RCL 10		
89 X↑2		
90 +		
91 +		
92 SQRT		
93 +		
94 STO 13		
95 FIX 0		Print 3F + M, allowable and % difference.
96 13		
97 STO 27		
98 11		

Step/Line Key Entry	Key Code	Comments
99 STO 28		
100 "3F+M="		
101 XEQ D		
102 RCL 05		Sum nozzle loads into reference nozzle registers.
103 ST+ 14		
104 RCL 06		
105 ST+ 15		
106 RCL 07		
107 ST+ 16		
108 RCL 08		
109 ST+ 17		
110 RCL 09		
111 ST+ 18		
112 RCL 10		
113 ST+ 19		
114 RCL 07		Calculate transferred MX sum into reference nozzle registers.
115 RCL 03		
116 *		
117 RCL 06		
118 RCL 04		
119 *		
120 -		
121 ST+ 17		
122 STO 27		
123 RCL 05		Calculate MY same as above.
124 RCL 04		
125 *		
126 RCL 07		
127 RCL 02		
128 *		
129 -		
130 ST+ 18		
131 STO 28		
132 RCL 06		Calculate MZ same as above.
133 RCL 02		
134 *		
135 RCL 05		
136 RCL 03		
137 *		
138 -		
139 ST+ 19		
140 STO 29		
141 SF 12		Print transferred MX, MY, and MZ (force-induced moments).
142 "TMX:TMY:TMZ"		
143 PRA		
144 CLA		
145 CF 12		
146 ARCL 27		

Step/Line	Key Entry	Key Code	Comments
147	"⊢ "		
148	ARCL 28		
149	"⊢ "		
150	ARCL 29		
151	PRA		
152	CLA		
153	ADV		
154	ADV		
155	GTO "AA"		
156	♦LBL "DD"		Put Dd multipliers in allowables registers (casing analysis).
157	50		
158	STO 21		
159	100		
160	STO 23		
161	125		
162	STO 22		
163	STO 25		
164	STO 26		
165	250		
166	STO 24		
167	9		Calculate Dc.
168	RCL 12		
169	SQRT		
170	X<=Y?		
171	GTO C		
172	18		
173	+		
174	3		
175	/		
176	♦LBL C		
177	FC? 01		
178	GTO E		
179	1.85		
180	*		Adjust for API-617.
181	♦LBL E		Calculate reference nozzle allowables.
182	ST* 21		
183	ST* 22		
184	ST* 23		
185	ST* 24		
186	ST* 25		
187	ST* 26		
188	6		Print applied forces and moments, allowables and % differences (casing analysis).
189	STO 00		
190	35		
191	STO 29		
192	14		
193	STO 27		
194	21		
195	STO 28		
196	♦LBL 10		
197	CLA		
198	ARCL IND 29		
199	XEQ D		
200	1		
201	ST+ 27		
202	ST+ 28		
203	ST+ 29		
204	DSE 00		
205	GTO 10		
206	ADV		Calculate 2F + M.
207	RCL 14		
208	X↑2		
209	RCL 15		
210	X↑2		
211	RCL 16		
212	X↑2		
213	+		
214	+		
215	SQRT		
216	2		
217	*		
218	RCL 17		
219	X↑2		
220	RCL 18		
221	X↑2		
222	RCL 19		
223	X↑2		
224	+		
225	+		
226	SQRT		
227	+		
228	STO 29		
229	29		Print 2F + M, allowable and % difference.
230	STO 27		
231	24		
232	STO 28		
233	"2F+M="		
234	XEQ D		
235	ADV		Stop.
236	ADV		
237	CLX		
238	FIX 3		
239	STOP		
240	♦LBL D		Print subroutine.
241	FIX 0		
242	ARCL IND 27		
243	PRA		
244	CLA		
245	"ALLOW="		
246	ARCL IND 28		
247	PRA		
248	CLA		
249	RCL IND 27		
250	RCL IND 28		
251	/		
252	100		
253	*		
254	ABS		
255	"="		
256	ARCL X		
257	"⊢%"		
258	PRA		
259	ADV		
260	RTN		
261	♦LBL "AC"		Error recovery routine.
262	PRBUF		
263	GTO "AA"		
264	END		

Chapter 13

Buried Concrete Thrust Block Sizing in Cohesionless Soils

Program TI-59-13

Introduction:

TI-59-13 is intended to assist the user in sizing buried thrust blocks primarily for buried piping anchors. The program will calculate the active earth pressure, passive earth pressure, and the earth pressure at rest, both above and below the water table, if any exists. TI-59-13 also determines the friction resistance of the block along the sides of the block and on the bottom. The analysis is accurate for cohesionless soils only and does not apply any factors of safety to the soil pressures calculated.

Nomenclature

Ten items must be supplied to the program by the user:

- HIGH: Thrust block height (see Figure 13.1) (ft)
- WIDE: Thrust block width (see Figure 13.1) (ft)
- DEEP: Thrust block depth (see Figure 13.1) (ft)
- *EI: Inverted elevation of the bottom of the block (ft)
- *WTBL: Water table depth (ft)
- SAT: Density of saturated soil (lbs/ft^3)
- USAT: Density of unsaturated soil (lbs/ft^3)
- FR D: Friction coefficient of dry soil
- FR W: Friction coefficient of wet soil
- ANGL: Internal angle of friction of soil (degrees)

The program calculates the following soil data from the input data:

- Ka: Coefficient of active soil pressure
- Ko: Coefficient of earth pressure at rest
- Kp: Coefficient of passive earth pressure

Using the input data and the above calculated data, the program produces the following output:

- FF S: Friction force on the sides of the block (lbs)
- FA: Active soil pressure applied to the block (lbs)
- FP: Passive soil pressure applied to the block (lbs)
- FF B: Friction force on the bottom of the block (lbs)
- FTOT: Total resisting force of the block (lbs)

Method:

The calculations performed are classical civil engineering soil equations taken from Introductory Soil Mechanics and Foundations: Geotechnical Engineering, 4th ed., by George F. Sowers. The program calculates all the soil coefficients and then determines what area of the block is under the water table, if there is any. For the friction force on the sides of the block, the earth pressure at rest is calculated at the bottom of the block, at the water table (if applicable), and at the top of the block. These forces outline two trapezoidal force distributions. From these distributions, the program determines the net force per unit length along the sides of the depth of the block, both above and below the water table. From the input value of DEEP, the net force on the sides of the block is determined. The force below the water table is then multiplied by the friction coefficient for wet soil, and the force above the water table is multiplied by the friction coefficient for dry soil. The sum of these two values is the total friction resistance on one side of the block. The value FF S is the friction resistance for both sides.

Similar force distributions are set up for the active soil pressure and the passive soil pressure. These forces represent the force of the soil acting against a wall that is moving *away* from the soil (active pressure) and the force of the soil acting on a wall that is moving *toward* the soil (passive pressure).

The final calculation performed by the program is

*These values are measured positively from the ground level downward.

determining the friction on the bottom of the block. Using a density of concrete of 150 pounds per cubic foot, the total weight of the block is calculated. Then the weight of the water displaced by the intrusion of the block into the water table is calculated and subtracted from the weight of the block. This final weight is then multiplied by the appropriate soil friction factor. Thus, the total resisting force is a sum of these parts. As the active soil pressure acts in line with the applied thrust force, its value is subtracted from the total. The program does not apply any safety factors to any of the values calculated, nor does it consider the friction resistance of the soil on the top of the block.

The following equations are used:

$$Ko = 1 - \sin(ANGL)$$

$$Ka = \tan^2(45 - ANGL/2)$$

$$Kp = \tan^2(45 + ANGL/2)$$

Earth pressure at rest:

$$Po = (\gamma_1 \cdot H_1 + (\gamma_2 - \gamma w) \cdot H_2(Ko) + \gamma w \cdot H_2$$

Active earth pressure:

$$Pa = (\gamma_1 \cdot H_1 + (\gamma_2 - \gamma w) \cdot H_2)(Ka) + \gamma w \cdot H_2$$

Passive earth pressure:

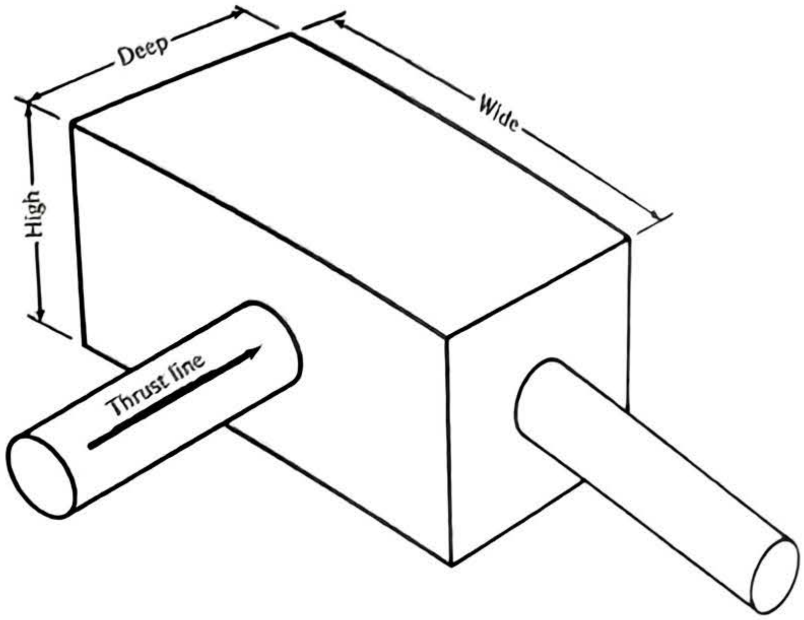
$$Pp = (\gamma_1 \cdot H_1 + (\gamma_2 - \gamma w) \cdot H_2)(Kp) + \gamma w \cdot H_2$$

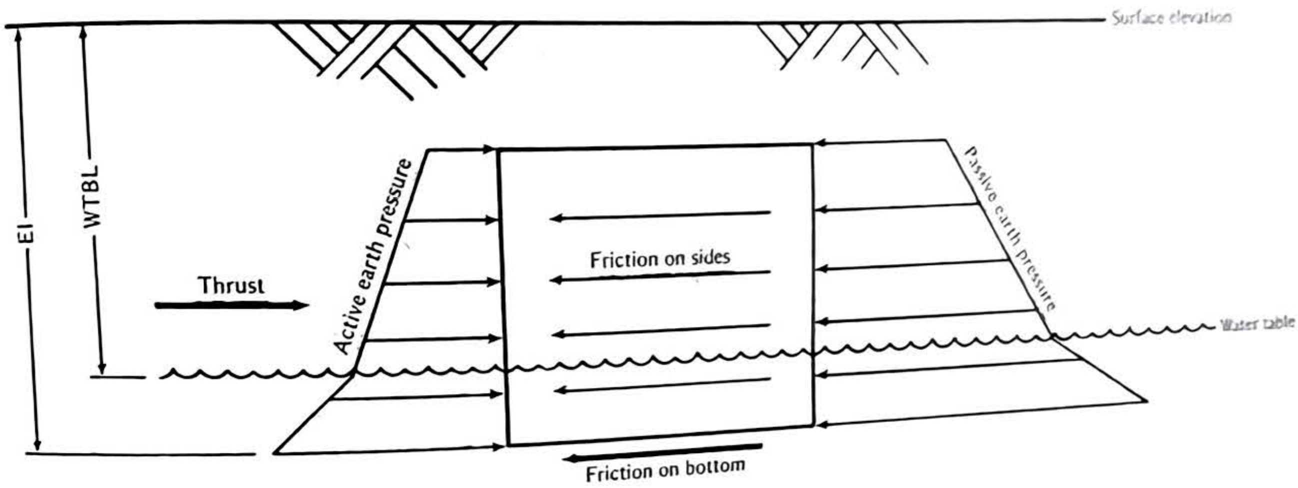
See Figure 13.1 for the definitions of H_1 and H_2.

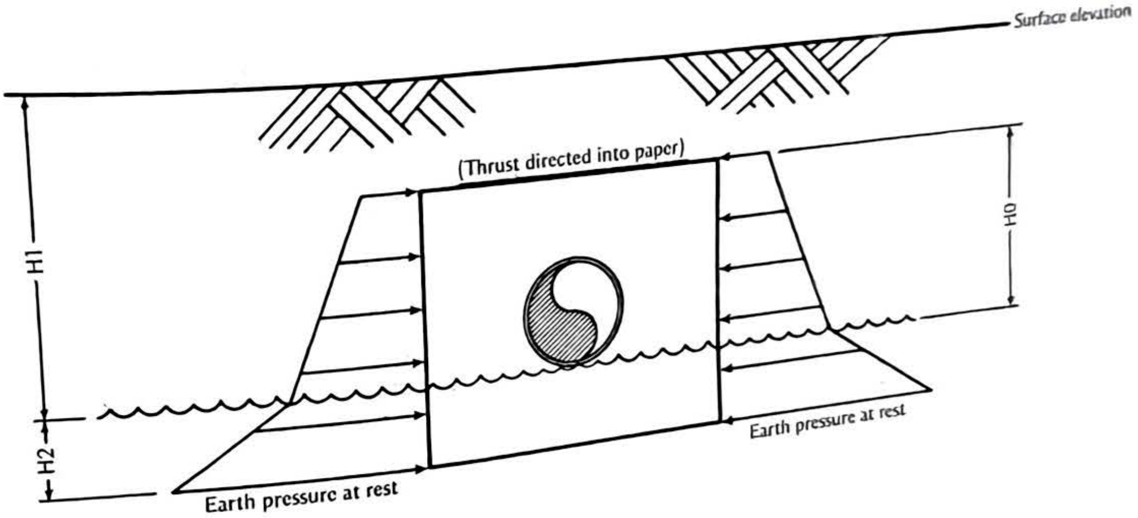
Limitations:

TI-59-13 does not apply any safety factors to the calculated values. The program will *not* correctly analyze a situation in which the top of the block is *below* the water table. The equations are to be used for cohesionless soils only: sand, gravel and sand, or sandy soils.

Figure 13.1 Explanation of Terms







User Instructions

Program Number TI-59-13 **Title** Buried Concrete Thrust Block Sizing

Step	Instructions	Input	Keystroke	Display
1	Read magnetic cards.		CLR	1, 2, or 3
2	Initialize program.		E	0
3	Input height of block.	HIGH	A	HIGH
4	Input width of block.	WIDE	A	WIDE
5	Input depth of block.	DEEP	A	DEEP
6	Input inverted elevation.	EI	A	EI
7	Input depth of water table.	WTBL	A	WTBL
8	Input saturated soil density.	SAT	A	SAT
9	Input unsaturated soil density.	USAT	A	USAT
10	Input friction coefficient of dry soil	FR D	A	FR D
11	Input friction coefficient of wet soil.	FR W	A	FR W
12	Input internal angle of friction of soil.	ANGL	A	ANGL
13	Execute.		B	FF S
				FA
				FP
				FF B
				FTOT

Data Register Contents

REGISTER	DATA	REGISTER	DATA
00		30	23242223
01	HIGH	31	43241617
02	WIDE	32	16171733
03	DEEP	33	1724
04	EI	34	43371427
05	WTBL	35	361337
06	SAT	36	41361337
07	USAT	37	21350016
08	FR D	38	21350043
09	FR W	39	13312227
10	ANGL	40	21210036
11		41	2113
12		42	2133
13	H0	43	21210014
14	H1	44	21373237
15	H2	45	
16	Ko	46	
17	Ka	47	
18	Kp	48	
19	F @ bottom	49	
20	F @ water table	50	
21	F @ top	51	
22	#/ft below water table	52	
23	#/ft above water table	53	
24		54	
25	FF S	55	
26	FA	56	
27	FP	57	
28	FF B	58	
29	FTOT	59	

Thrust block above water table.

20.	HIGH
15.	WIDE
10.	DEEP
25.	EI
30.	WTBL
130.	SAT
100.	USAT
0.3	FR D
0.2	FR W
35.	ANGL
76756.	FF S
-121946.	FA
1660578.	FP
135000.	FF B
1750388.	FTOT

Bottom of thrust at water table line.

20.	HIGH
15.	WIDE
10.	DEEP
25.	EI
25.	WTBL
130.	SAT
100.	USAT
0.3	FR D
0.2	FR W
35.	ANGL
76756.	FF S
-121946.	FA
1660578.	FP
90000.	FF B
1705388.	FTOT

Thrust block partially submerged into water table.

20.	HIGH
15.	WIDE
10.	DEEP
25.	EI
15.	WTBL
130.	SAT
100.	USAT
0.3	FR D
0.2	FR W
35.	ANGL
69416.	FF S
-162160.	FA
1617706.	FP
71280.	FF B
1596242.	FTOT

Top of thrust block at water table line.

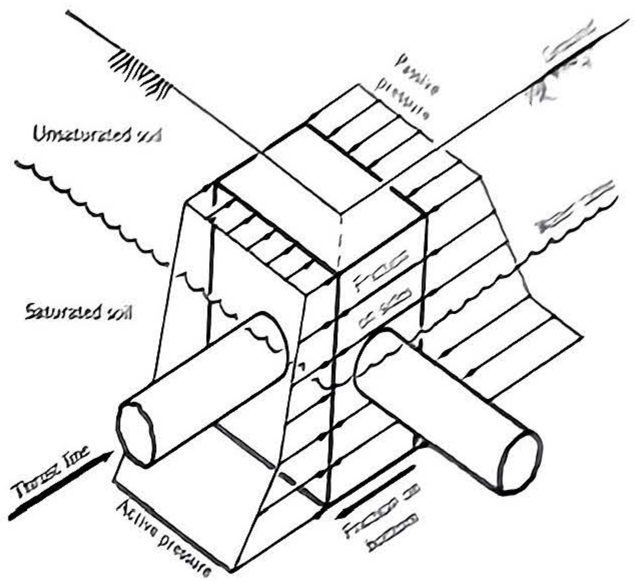
20.	HIGH
15.	WIDE
10.	DEEP
25.	EI
5.	WTBL
130.	SAT
100.	USAT
0.3	FR D
0.2	FR W
35.	ANGL
90038.	FF S
-282805.	FA
1489093.	FP
52560.	FF B
1348885.	FTOT

Example Calculation

ANCHOR BLOCK DESIGN (LINES BURIED IN COHESIONLESS SOILS)

Considerations:

- Thrust force
- Block dimensions
- Water table, if any
- Earth pressure at rest
- Passive earth pressure
- Active earth pressure
- Friction force acting on bottom face
- Friction force acting on sides



Earth pressure at rest:

$$Po = [\gamma_1 H_1 + (\gamma_2 - \gamma w)H_2](1 - \sin\phi) + \gamma w H_2$$

Passive earth pressure:

$$Pp = [\gamma_1 H_1 + (\gamma_2 - \gamma w)H_2]\tan^2\left(45 + \frac{\phi}{2}\right) + \gamma w H_2$$

Active Earth Pressure

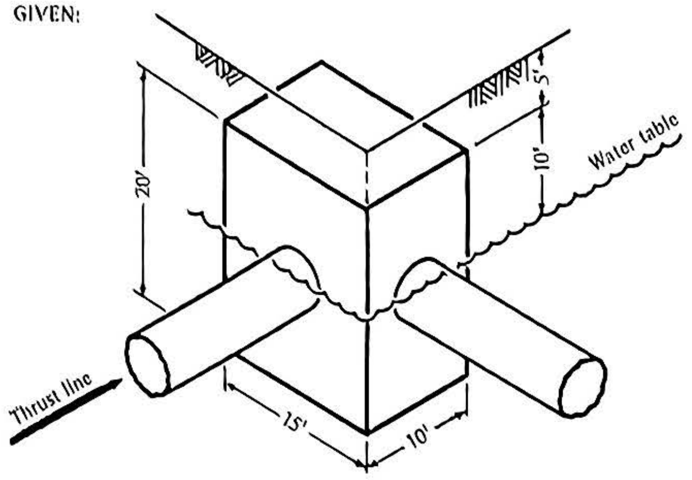
$$Pa = [\gamma_1 H_1 + (\gamma_2 - \gamma w)H_2]\tan^2\left(45 - \frac{\phi}{2}\right) + \gamma w H_2$$

Definitions:

γ_1 = Unsaturated soil density
γ_2 = Saturated soil density
Z = Depth of point where pressure is wanted
Zw = Depth of water table
γw = Density of water
ϕ = Angle of internal friction
H_1 = Depth of unsaturated soil
H_2 = Depth of saturated soil = (Z − Zw)

Sample Problem:
Design a Thrust Block That Will Restrain a Force of 1,500,000 lbs.

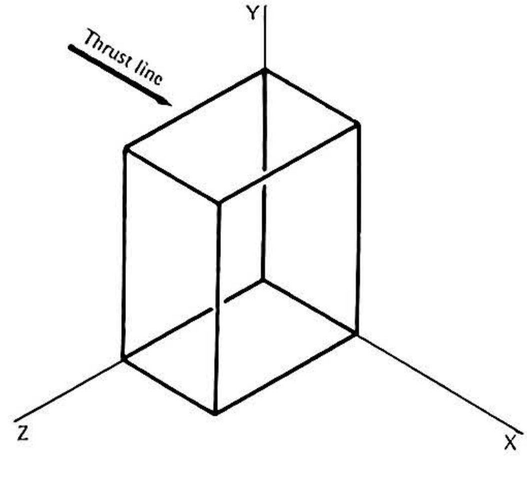
GIVEN:



γ_1 = (Unsaturated weight of soil) = 100 lb/ft^3
γ_2 = (Saturated weight of soil) = 130 lb/ft^3
ϕ = (Angle of internal friction) = 35° (sand)
μ_1 = (Friction coefficient of Unsaturated soil) = 0.3
μ_2 = (Friction coefficient of saturated soil) = 0.2

Solution:

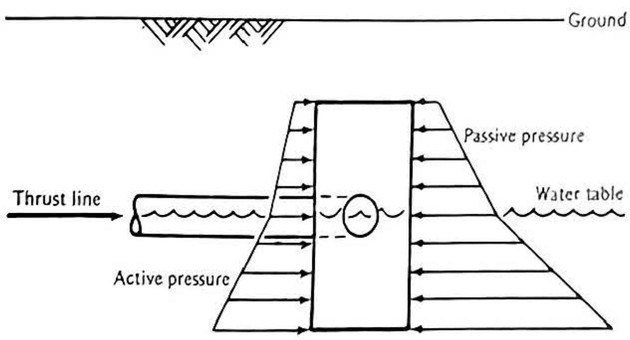
Assume the dimensions of the sides of the block and solve for the total restraining force. If the restraining force is greater than the applied thrust, then the block is overdesigned and could be sized down. If, on the other hand, the restraining force is less than the thrust applied, then increase one dimension of the block until the two forces are more or less equal.



Note that if the size of the block is insufficient to restrain the thrust, it is more advantageous to increase the size of the block in the Z-direction, unless the Y-dimension is increased while the top of the block remains at the same underground elevation.

For the sample problem, let us assume that for the block, Y = 20′, X = 10′, and Z = 15′.

Now, looking at the X-Y plane the pressure distribution diagram would be as follows:



The passive, active, the rest pressures must be found at the top and bottom of the block and at the water table level.

Pressure at Rest (Pr):

(Bottom) $Pr = [\gamma_1 H_1 + (\gamma_2 - \gamma w)H_2(1 - \sin\phi) + \gamma w H_2)$
$= [100(15) + (130 - 62.4)\ 10\ (1 - \sin 35^\circ)] + 62.4\ (10)$
$= \underline{1551.90}\ \text{lb/ft}^2$

Note that H_2 becomes zero at and above the water table:

(Water Table) $Pr = [\gamma_1 H_1](1 - \sin\phi)$
$= [100(15)](1 - \sin 35)$
$= \underline{639.64}\ \text{lb/ft}^2$

(Top) $Pr = (100\ (5))\ (1 - \sin 35)$
$= \underline{213.21}\ \text{lb/ft}^2$

Similarly for passive pressure (Pp):

(Bottom) $Pp = \underline{8{,}653.81}\ \text{lb/ft}^2$

(Water Table) $Pp = \underline{5{,}535.26}\ \text{lb/ft}^2$

(Top) $Pp = \underline{1{,}845.09}\ \text{lb/ft}^2$

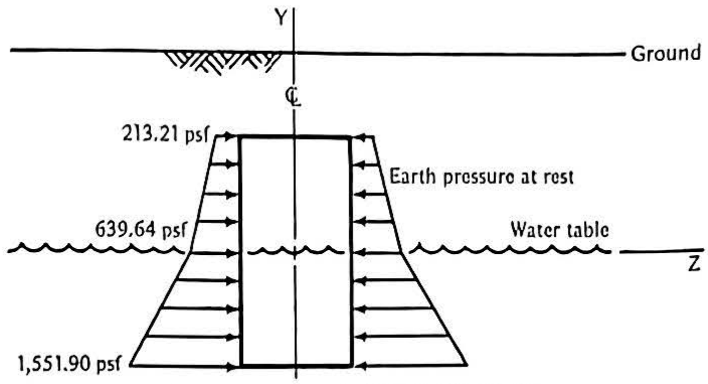
Active earth pressure (Pa):

(Bottom) $Pa = \underline{1{,}213.67}\ \text{lb/ft}^2$

(Water Table) $Pa = \underline{406.49}\ \text{lb/ft}^2$

(Top) $Pa = \underline{135.50}\ \text{lb/ft}^2$

Now calculate resisting friction force on the sides.



PRESSURE DISTRIBUTION DIAGRAM

The areas under the triangles will provide the resulting force per linear foot acting on the sides.

$$\text{Area above water table} = \frac{(639.64 - 213.21)\,10}{2} + 213.21(10).$$
$$= 4{,}264.25 \text{ lb/ft}$$

Multiplying this times the block dimension parallel to the thrust or the X-dimension, we obtain the total force acting on one side *above* the water table:

FR (force due to earth pressure at rest) = 4,264.25(10) = 42,642.50 lbs
Ff (friction force) = 0.3 (42,642.5) = 12,792.75 lbs
Ff (two sides) = 12,792.75(2) = <u>25,585.50</u> lbs

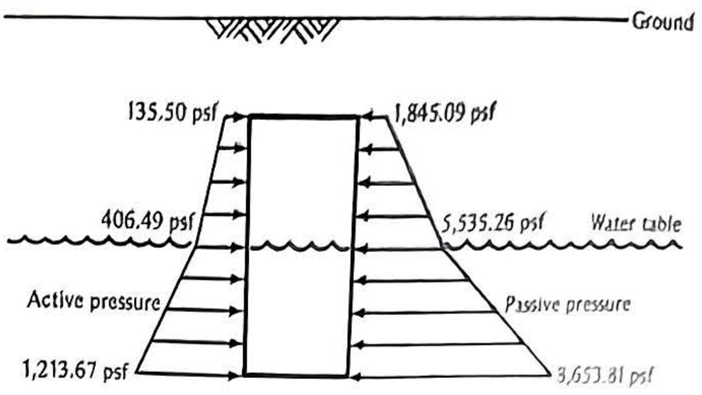
Similarly for the component below the water table:

$$\text{Area} = \frac{(1{,}551.90 - 639.64)10}{2} + 639.64(10)$$
$$= 10{,}957.70 \text{ lb/ft}$$

Again, total force acting on one side *below* the water table:

Fr = 10,957.70(10) = 109,577 lbs
Ff = 0.2 (109,577) = 21,915.4 lbs
Ff (two sides) = 21,915.4(2) = <u>43,830.80</u> lbs

Following a similar procedure, the active and passive components of the resisting force are found.



PRESSURE DISTRIBUTION DIAGRAM

Active pressure:

$$\text{Area} = \frac{(1{,}213.67 - 406.49)10}{2} + 406.49(10) + \frac{(406.49 - 135.5)10}{2} + 135.5(10)$$
$$= 10{,}810.75 \text{ lb/ft}$$
$$FA = 10{,}810.75(15) = \underline{162{,}161.25} \text{ lbs}$$

Passive pressure:

$$\text{Area} = \frac{(8{,}653.81 - 5{,}535.26)10}{2} + 5{,}535.26(10) + \frac{(5{,}535.26 - 1{,}845.09)10}{2} + 1{,}845.09(10)$$
$$= 107{,}847.10 \text{ lb/ft}$$
$$FP = 107{,}847.10(15) = \underline{1{,}617{,}706.5} \text{ lbs}$$

Finally, we must account for the friction force acting on the bottom face of the block.

Concrete = 150 lb/ft^3
Volume of block = $10 \times 20 \times 15 = 3{,}000$ ft^3

Total weight of concrete = 150(3,000) = 450,000 lbs.

To this we must subtract the displaced weight of water to account for the buoyancy effect on the portion of the block below the water table.

w = 62.4 lb/ft^3
Volume under saturated soil = $10 \times 10 \times 15 =$ 1,500 ft^3
Weight of water displaced = 62.4(1,500) = 93,600 lbs
Total weight = 450,000 − 93,600 = 356,400 lbs
FF = 356,400(0.2) = $\underline{71{,}280}$ lbs

Note that the friction force on the top face is ignored.
Total resisting force:

$$FTOT = (FF\ S) + (FP) - (FA) + (FF\ B)$$
$$= (25{,}586 + 43{,}831) + (1{,}617{,}707) - (162{,}161) + (71{,}280)$$
$$= \underline{1{,}596{,}243} \text{ lbs}$$

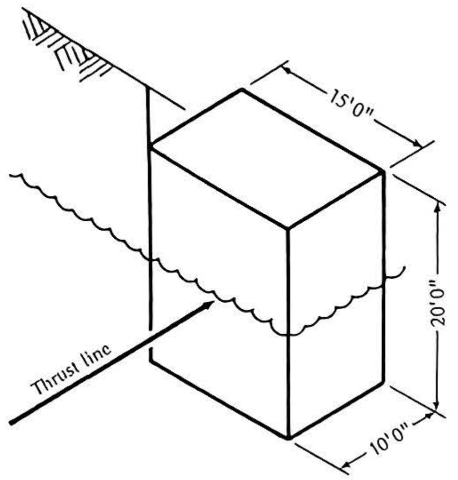
Total Force = 1,596,243 > 1,500,000 = Thrust
∴Thrust block is adequate

Note that the passive force is the highest component of the total resisting force.

Sample Problem

Program: TI-59-13

EI = 25'
WTBL = 15'
SAT = 130 lbs/ft^3
UNSAT = 100 lbs/ft^3
FR D = 0.3
FR W = 0.2
ANGL = 35°



Step	Input	Key Stroke	Display	Printer		Comments
1		E	0			Initialize program.
2	20	A	20.	20.	HIGH	Store HIGH in R01; print.
3	15	A	15.	15.	WIDE	Store WIDE in R02; print.
4	10	A	10.	10.	DEEP	Store DEEP in R03; print.
5	25	A	25.	25.	EI	Store EI in R04; print.
6	15	A	15.	15.	WTBL	Store WTBL in R05; print.
7	130	A	130.	130.	SAT	Store SAT in R06; print.
8	100	A	100.	100.	USAT	Store USAT in R07; print.
9	.3	A	0.3	0.3	FR D	Store FR D in R08; print.
10	.2	A	0.2	0.2	FR W	Store FR W in R09; print.
11	35	A	35.	35.	ANGL	Store ANGL in R10; print.
12		B		69416. -162160. 1617706. 71280. 1596242.	FF S FA FP FF B FTOT	The program determines the values of H_1, H_2, and H_0. Then the various forces (active, passive, earth pressure at rest) are determined at the bottom of the block, at the water table, and at the top of the block. The program sets up the trapezoidal pressure distributions and finds the total force applied to the block, above and below the water line. For the friction on the sides, the earth pressure at rest is multiplied by the friction factors, wet and dry depending on which side of the water table, and derives the total frictional resistance on the sides of the block. The friction on the bottom of the block is found by calculating the volume of the block and multiplying it by

Step	Input	Key Stroke	Display	Printer	Comments
					150 lbs/ft^3 (for concrete). This weight is decreased by the volume of water displaced by the intrusion of the block into the water table. The residual weight is multiplied by the correct friction factor, and the result is the frictional resistance on the bottom of the block. The final results and the total resisting force of the block are printed. This value is the sum of the above values, where all the factors are added except the active soil pressure, which is subtracted.

Coding Form

Program Number TI-59-13 **Title** Buried Concrete Thrust Block Sizing

Loc	Code	Key	Comments
000	76	LBL	Input routine.
001	11	A	Uses R00 and R11
002	32	X:T	as pointers.
003	01	1	
004	44	SUM	
005	11	11	
006	69	OP	
007	20	20	
008	73	RC*	
009	11	11	
010	69	OP	
011	04	04	
012	32	X:T	
013	69	OP	
014	06	06	
015	72	ST*	
016	00	00	
017	91	R/S	
018	76	LBL	Subroutine:
019	16	A'	Calculates the
020	87	IFF	soil pressure at
021	01	01	the bottom of the
022	47	CMS	block when the
023	43	RCL	water table is at or
024	07	07	above the bottom
025	65	×	of the block. If flag
026	43	RCL	1 is set (no
027	14	14	intrusion into the
028	85	+	water table), this
029	53	(	section is skipped.
030	43	RCL	Stored in R19.
031	06	06	
032	75	-	
033	06	6	
034	02	2	
035	93	.	
036	04	4	
037	54	)	
038	65	×	
039	43	RCL	
040	15	15	
041	54	)	
042	65	×	
043	73	RC*	
044	00	00	
045	85	+	
046	06	6	
047	02	2	
048	93	.	
049	04	4	
050	65	×	
051	43	RCL	
052	15	15	
053	95	=	
054	42	STO	
055	19	19	
056	76	LBL	Calculates the soil
057	47	CMS	pressure at the
058	43	RCL	water tale. If Flag 1
059	14	14	is set, this point

Loc	Code	Key	Comments
060	65	×	corresponds to the
061	43	RCL	bottom of the
062	07	07	block. Stored in
063	65	×	R20.
064	73	RC*	The pressure at the
065	00	00	top of the block is
066	95	=	stored in R21.
067	42	STO	
068	20	20	
069	43	RCL	
070	04	04	
071	75	-	
072	43	RCL	
073	01	01	
074	54	)	
075	65	×	
076	43	RCL	
077	07	07	
078	65	×	
079	73	RC*	
080	00	00	
081	95	=	
082	42	STO	
083	21	21	
084	87	IFF	The area in the
085	01	01	trapezoid under
086	38	SIN	the water table is
087	43	RCL	calculated, giving a
088	19	19	force-per-foot
089	75	-	value for the earth
090	43	RCL	pressure.
091	20	20	If Flag 1 is set,
092	54	)	this section is
093	55	÷	skipped. Stored in
094	02	2	R22.
095	85	+	
096	43	RCL	
097	20	20	
098	54	)	
099	65	×	
100	43	RCL	
101	15	15	
102	95	=	
103	42	STO	
104	22	22	
105	76	LBL	The area in the
106	38	SIN	trapezoid above
107	43	RCL	the water table is
108	20	20	calculated and
109	75	-	stored in R23.
110	43	RCL	
111	21	21	
112	54	)	
113	55	÷	
114	02	2	
115	85	+	
116	43	RCL	
117	21	21	
118	54	)	
119	65	×	

Loc	Code	Key	Comments
120	43	RCL	
121	13	13	
122	95	=	
123	42	STO	
124	23	23	
125	92	RTN	
126	76	LBL	Main program.
127	12	B	
128	43	RCL	
129	04	04	The level of the
130	75	-	water table is
131	43	RCL	determined in
132	05	05	relation to the
133	95	=	bottom of the
134	29	CP	concrete. If the
135	77	GE	block does not
136	24	CE	intrude into the
137	32	X:T	water table, Flag 1
138	86	STF	is set.
139	01	01	
140	76	LBL	
141	24	CE	
142	42	STO	
143	15	15	
144	94	+/-	H_1 is stored in R14.
145	85	+	Above, H_2 is stored
146	43	RCL	in R15.
147	04	04	
148	95	=	
149	42	STO	
150	14	14	
151	43	RCL	H_0 is stored in R13.
152	01	01	
153	75	-	
154	43	RCL	
155	15	15	
156	95	=	
157	42	STO	
158	13	13	
159	01	1	Ko is calculated
160	75	-	and stored in R16.
161	43	RCL	
162	10	10	
163	38	SIN	
164	95	=	
165	42	STO	
166	16	16	
167	04	4	Ka is calculated
168	05	5	and stored in R17.
169	75	-	
170	43	RCL	
171	10	10	
172	55	÷	
173	02	2	
174	95	=	
175	30	TAN	
176	33	X²	
177	42	STO	
178	17	17	
179	04	4	

Loc	Code	Key	Comments
180	05	5	Kp is calculated and stored in R18.
181	85	+	
182	43	RCL	
183	10	10	
184	55	÷	
185	02	2	
186	95	=	
187	30	TAN	
188	33	X²	
189	42	STO	
190	18	18	
191	01	1	Set pointer to calculate earth pressure at rest.
192	06	6	
193	42	STO	
194	00	00	
195	16	A'	
196	87	IFF	The force of the earth on the sides of the block under the water table is calculated. If Flag 1 is set, this section is skipped.
197	01	01	
198	17	B'	
199	43	RCL	
200	22	22	
201	65	×	
202	43	RCL	
203	03	03	
204	65	×	
205	43	RCL	
206	09	09	
207	95	=	
208	85	+	
209	76	LBL	
210	17	B'	
211	43	RCL	The force of the earth on the sides of the block above the water table is calculated. The friction force is stored in R25.
212	23	23	
213	65	×	
214	43	RCL	
215	03	03	
216	65	×	
217	43	RCL	
218	08	08	
219	95	=	
220	65	×	
221	02	2	
222	95	=	
223	42	STO	
224	25	25	
225	69	OP	Increment pointer to calculate active earth pressure. The force of the earth on the front of the block below the water table is calculated.
226	20	20	
227	16	A'	
228	87	IFF	
229	01	01	
230	18	C'	
231	43	RCL	
232	22	22	
233	65	×	
234	43	RCL	
235	02	02	
236	95	=	
237	85	+	
238	76	LBL	
239	18	C'	

Loc	Code	Key	Comments
240	43	RCL	Force above water table is calculated. Active earch force is stored in R26.
241	23	23	
242	65	×	
243	43	RCL	
244	02	02	
245	95	=	
246	42	STO	
247	26	26	
248	69	OP	Increment pointer for passive pressure. Earth pressure on the back of the block under the water table is calculated.
249	20	20	
250	16	A'	
251	87	IFF	
252	01	01	
253	19	D'	
254	43	RCL	
255	22	22	
256	65	×	
257	43	RCL	
258	02	02	
259	95	=	
260	85	+	
261	76	LBL	
262	19	D'	
263	43	RCL	Force above the water table is calculated. Passive earth force is stored in R27.
264	23	23	
265	65	×	
266	43	RCL	
267	02	02	
268	95	=	
269	42	STO	
270	27	27	
271	43	RCL	Weight of concrete block is stored in R28.
272	01	01	
273	65	×	
274	43	RCL	
275	02	02	
276	65	×	
277	43	RCL	
278	03	03	
279	65	×	
280	01	1	
281	05	5	
282	00	0	
283	95	=	
284	42	STO	
285	28	28	
286	43	RCL	Buoyancy of the water displaced by the block (if any) is subtracted from R28.
287	15	15	
288	65	×	
289	43	RCL	
290	02	02	
291	65	×	
292	43	RCL	
293	03	03	
294	65	×	
295	06	6	
296	02	2	
297	93	.	
298	04	4	
299	95	=	

Loc	Code	Key	Comments
300	94	+/-	
301	44	SUM	
302	28	28	
303	87	IFF	The program chooses the appropriate friction factor and multiplies it into R28.
304	01	01	
305	10	E'	
306	43	RCL	
307	09	09	
308	61	GTO	
309	23	LNX	
310	76	LBL	
311	10	E'	
312	43	RCL	
313	08	08	
314	76	LBL	
315	23	LNX	
316	49	PRD	
317	28	28	
318	98	ADV	Friction on the sides of the block is printed.
319	43	RCL	
320	40	40	
321	69	OP	
322	04	04	
323	43	RCL	
324	25	25	
325	58	FIX	
326	00	00	
327	69	OP	
328	06	06	
329	43	RCL	Active earth force is printed.
330	41	41	
331	69	OP	
332	04	04	
333	43	RCL	
334	26	26	
335	94	+/-	
336	69	OP	
337	06	06	
338	43	RCL	Passive earth force is printed.
339	42	42	
340	69	OP	
341	04	04	
342	43	RCL	
343	27	27	
344	69	OP	
345	06	06	
346	43	RCL	Friction on the bottom of the block is printed.
347	43	43	
348	69	OP	
349	04	04	
350	43	RCL	
351	28	28	
352	69	OP	
353	06	06	
354	98	ADV	Total resisting force of the block is printed.
355	43	RCL	
356	44	44	
357	69	OP	
358	04	04	
359	43	RCL	

Loc	Code	Key	Comments
360	25	25	
361	75	-	
362	43	RCL	
363	26	26	
364	85	+	
365	43	RCL	
366	27	27	
367	85	+	
368	43	RCL	
369	28	28	
370	95	=	
371	69	OP	
372	06	06	
373	98	ADV	
374	98	ADV	
375	98	ADV	
376	98	ADV	
377	76	LBL	Initialize program.
378	15	E	Reset Flag 1.
379	22	INV	Set pointers for
380	86	STF	input routine.
381	01	01	
382	22	INV	
383	58	FIX	
384	02	2	
385	09	9	
386	42	STO	
387	11	11	
388	25	CLR	
389	42	STO	
390	00	00	
391	91	R/S	

Thrust Block Calculations

Thrust block height (ft)
Thrust block width (ft)
Thrust block depth (ft)
Inverted elevation of bottom of block (ft)
Water table depth of (ft)
Density of saturated soil (lbs/ft^3)
Density of unsaturated soil (lbs/ft^3)
Friction coefficient of dry soil
Friction coefficient of wet soil
Internal angle of friction for soil (degrees)

Friction force on the sides of the block (lbs)
Active soil pressure (lbs)
Passive soil pressure (lbs)
Friction force on the bottom of the block (lbs)

Total resisting force of the block (lbs)

Warning: This analysis does not extend to the case where the water table is *above* the top of the block.

Program HP-41CV-13: Buried Thrust Block Sizing in Cohesionless Soils

Introduction:

HP-41CV-13 is intended to assist the user in sizing buried thrust blocks primarily for buried piping anchors. The program will calculate the active earth pressure, passive earth pressure, and the earth pressure at rest, both above and below the water table, if any exists. HP-41CV-13 also determines the friction resistance of the block along the sides of the block and on the bottom. The analysis is accurate for cohesionless soils only and does not apply any factors of safety to the soil pressures calculated.

Nomenclature:

Ten items must be supplied to the program by the user:

HIGH:	Thrust block height (see Figure 13.2) (ft)
WIDE:	Thrust block width (see Figure 13.2) (ft)
DEEP:	Thrust block depth (see Figure 13.2) (ft)
*El:	Inverted elevation of the bottom of the block (ft)
*WTBL:	Water table depth (ft)
d.SAT:	Density of saturated soil (lbs/ft^3)
d.USAT:	Density of unsaturated soil (lbs/ft^3)
FR,DRY:	Friction coefficient of dry soil
FR,WET:	Friction coefficient of wet soil
$\measuredangle$:	Internal angle of friction of soil (degrees)

The program calculates the following soil data from the input data:

Ka:	Coefficient of active soil pressure
Ko:	Coefficient of earth pressure at rest
Kp:	Coefficient of passive earth pressure

Using the input data and the above calculated data, the program produces the following output:

FRICTION (SIDES):	Friction force on the sides of the block (lbs)
ACTIVE PRESSURE:	Active earth pressure applied the block (lbs)
PASSIVE PRESSURE:	Passive earth pressure applied to the block (lbs)
FRICTION (BOTTOM):	Friction force on the bottom of the block (lbs)
TOTAL:	Total resisting force of the block (lbs)

Method:

The calculations performed are classical civil engineering soil equations taken from Introductory Soil Mechanics and Foundations: Geotechnical Engineering, 4th ed., by George F. Sowers. The program calculates all the soil coefficients and then determines what area of the block is under the water table, if there is any. For the friction force on the sides of the block, the earth pressure at rest is calculated at the bottom of the block, at the water table (if applicable), and at the top of the block. These forces outline two trapezoidal force distributions. From these distributions, the program determines the net force per unit length along the sides of the depth of the block, both above and below the water table. From the input value of DEEP, the net force on the sides of the block is determined. The force below the water table is then multiplied by the friction coefficient for wet soil, and the force above the water table is multiplied by the friction coefficient for dry soil. The sum of these two values is the total friction resistance on one side of the block.

Similar force distributions are set up for the active soil pressure and the passive soil pressure. These forces represent the force of the soil acting against a wall that is moving *away* from the soil (active pressure) and the force of the soil acting on a wall that is moving *toward* the soil (passive pressure).

The final calculation performed by the program is determining the friction on the bottom of the block. Using a density of concrete of 150 pounds per cubic foot, the total weight of the block is calculated. Then the weight of the water displaced by the intrusion of the block into the water table is calculated and subtracted from the weight of the block. This final weight is then multiplied by the appropriate soil friction factor. Thus, the total resisting force is a sum of these parts. As the active soil pressure acts in line with the applied thrust force, its value is subtracted form the total.

The program does not apply any safety factors to any of the values calculated, nor does it consider the friction resistance of the soil on the top of the block.

---

*These values are measured positively from the ground level downward.

The following equations are used:

$$Ko = 1 - \sin(ANGL)$$
$$Ka = \tan^2(45 - ANGL/2)$$
$$Kp = \tan^2(45 + ANGL/2)$$

Earth pressure at rest:

$$Po = (\gamma 1 \cdot H_1 + (\gamma_2 - \gamma w) \cdot H_2)(Ko) + \gamma w \cdot H_2$$

Active earth pressure:

$$Pa = (\gamma 1 \cdot H_1 + (\gamma_2 - \gamma w) \cdot H_2)(Ka) + \gamma w \cdot H_2$$

Passive earth pressure:

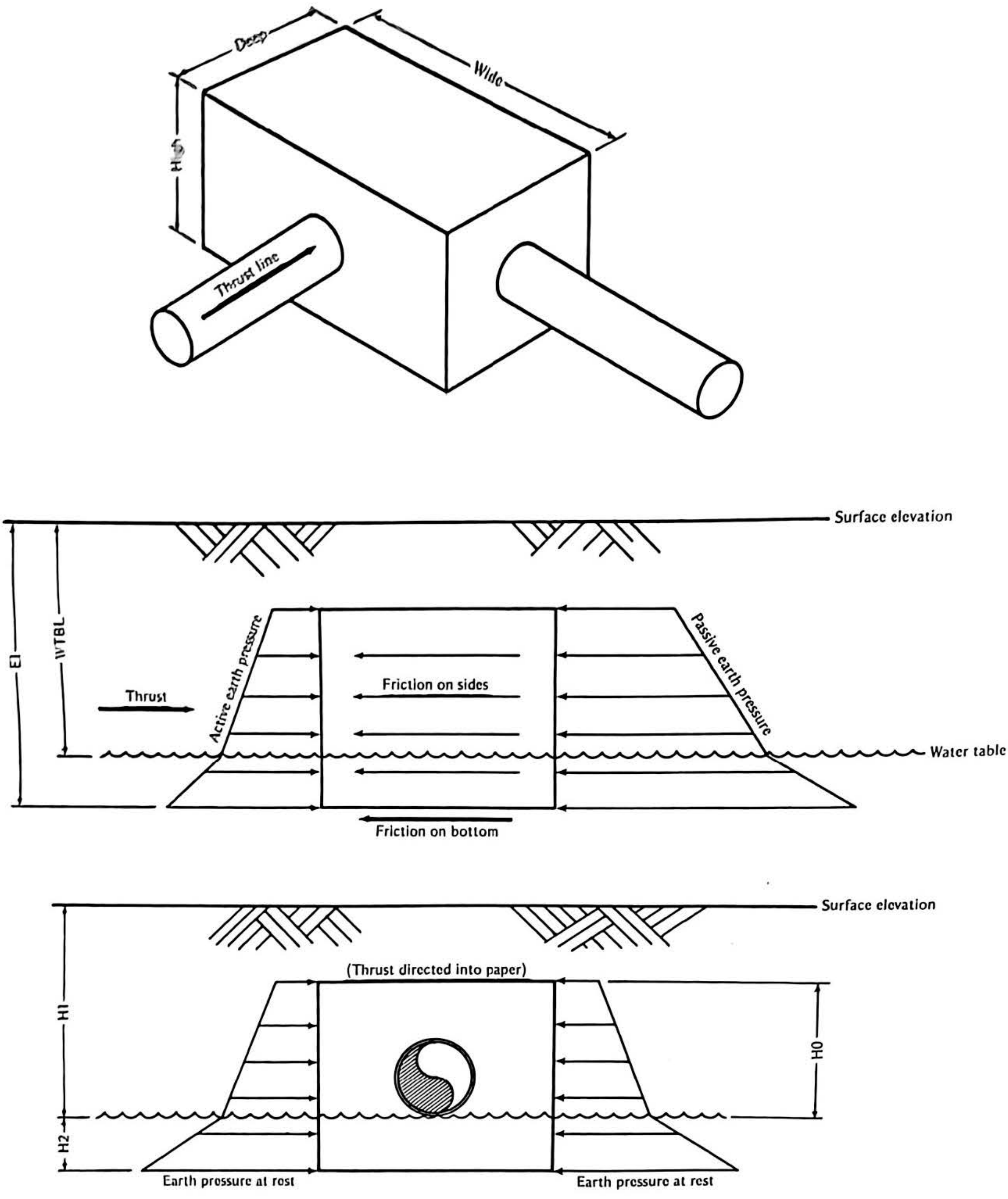
$$Pp = (\gamma 1 \cdot H_1 + (\gamma_2 - \gamma w) \cdot H_2)(Kp) + \gamma w \cdot H_2$$

See Figure 13.2 for the definitions of H_1 and H_2

Limitations:

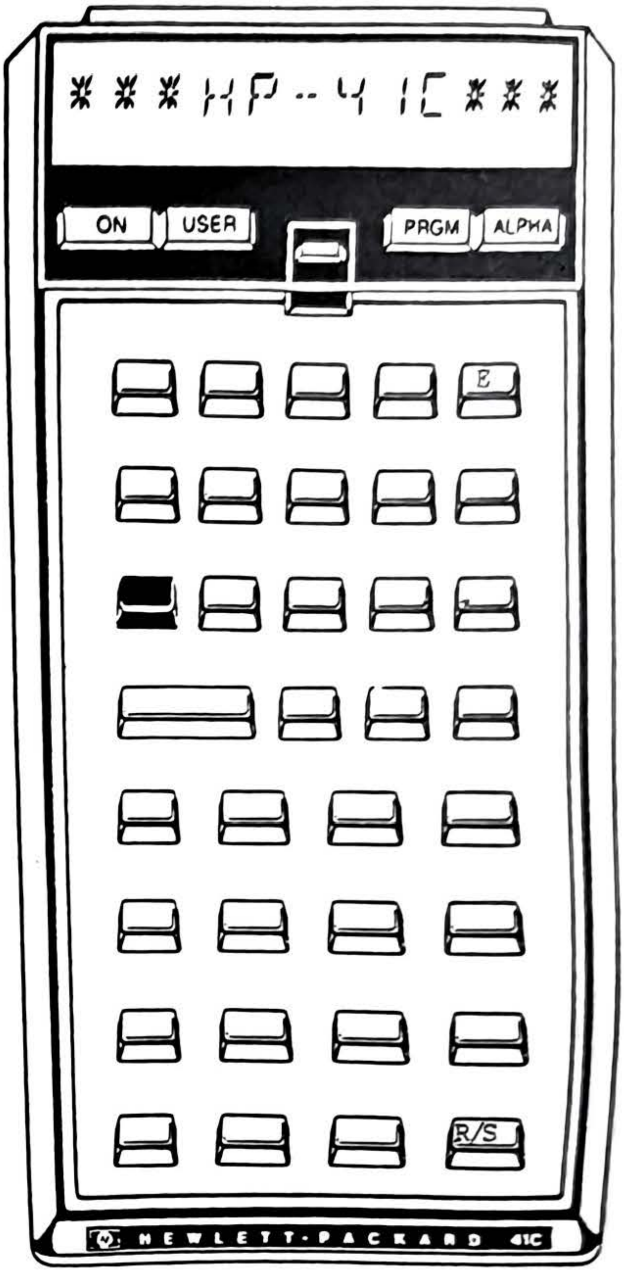
HP-41CV-13 does not apply any safety factors to the calculated values. The program will *not* correctly analyze a situation in which the top of the block is *below* the water table. The equations are to be used for cohesionless soils only: sand, gravel and sand, or sandy soils.

Figure 13.2 Explanation of Terms

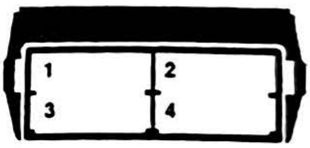


Keyboard Card Labeling

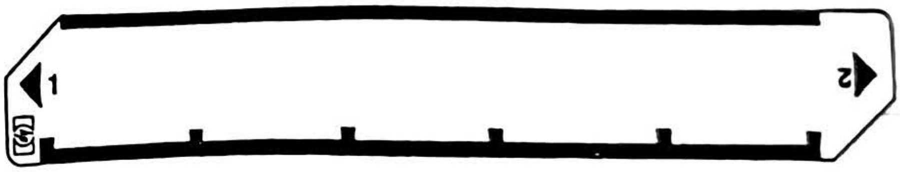
KEYBOARD



SYSTEM CONFIGURATION



CARD



User Instructions

Program Number HP-41CV-13 **Title** Buried Concrete Thrust Block Sizing

Step	Instructions	Input	Keystroke	Display
1	Read in magnetic cards.			
2	Initialize program.		E	HIGH=
3	Input HIGH.	HIGH	R/S	WIDE=
4	Input WIDE.	WIDE	R/S	DEEP=
5	Input DEEP.	DEEP	R/S	EI=
6	Input EI.	EI	R/S	WTBL=
7	Input WTBL.	WTBL	R/S	d.SAT=
8	Input d.SAT.	d.SAT	R/S	d.USAT=
9	Input d.USAT.	d.USAT	R/S	FR,DRY=
10	Input FR,DRY.	FR,DRY	R/S	FR,WET
11	Input FR,WET.	FR,WET	R/S	∡=
12	Input ∡.	∡	R/S	TOTAL

Registers, Flags, Assignments

Program Number HP-41CV-13 **Title** Buried Concrete Thrust Block Sizing

DATA REGISTERS

00	Pointer
01	HIGH
02	WIDE
03	DEEP
04	EI
05	WTBL
06	d.SAT
07	d.USAT
08	FR,DRY
09	FR,WET
10	4
11	
12	
13	H_0
14	H_1
15	H_2
16	Ko
17	Ka
18	Kp
19	Force @ bottom
20	Force @ water table
21	Force at top
22	#/ft below water table
23	#/ft above water table
24	
25	FRICTION (sides)
26	ACTIVE PRESSURE
27	PASSIVE PRESSURE
28	FRICTION (BOTTOM)
29	TOTAL
30	
31	
32	
33	
34	
35	
36	
37	
38	

DATA REGISTERS

39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	

FLAGS

#	Init S/C	Set Indicates	Clear Indicates
1	C	Block not *in* the water table.	Block in the water table.

ASSIGNMENTS

Label	Key	Function	Key
TB	15 (E)		

Example of a case where the water table is *at* the bottom of the block.

```
HIGH= 20.000
WIDE= 15.000
DEEP= 10.000
EI= 25.000
WTBL= 25.000
d.SAT= 130.000
d.USAT= 100.000
FR,DRY= 0.300
FR,WET= 0.200
∡= 35.000

FRICTION
      SIDES=76,756. LB
     BOTTOM=90,000. LB
PASSIVE
PRESSURE
          1,660,578. LB
ACTIVE
PRESSURE
           -121,946. LB
TOTAL
          1,705,388. LB
```

Example of a case where the water table is *below* the bottom of the block.

```
HIGH= 20.000
WIDE= 15.000
DEEP= 10.000
EI= 25.000
WTBL= 30.000
d.SAT= 130.000
d.USAT= 100.000
FR,DRY= 0.300
FR,WET= 0.200
∡= 35.000

FRICTION
      SIDES=76,756. LB
    BOTTOM=135,000. LB
PASSIVE
PRESSURE
          1,660,578. LB
ACTIVE
PRESSURE
           -121,946. LB
TOTAL
          1,750,388. LB
```

Example of a case where the block is partially submerged in the water table.

```
HIGH= 20.000
WIDE= 15.000
DEEP= 10.000
EI= 25.000
WTBL= 15.000
d.SAT= 130.000
d.USAT= 100.000
FR,DRY= 0.300
FR,WET= 0.200
∡= 35.000

FRICTION
      SIDES=69,416. LB
     BOTTOM=71,280. LB
PASSIVE
PRESSURE
          1,617,706. LB
ACTIVE
PRESSURE
           -162,160. LB
TOTAL
          1,596,242. LB
```

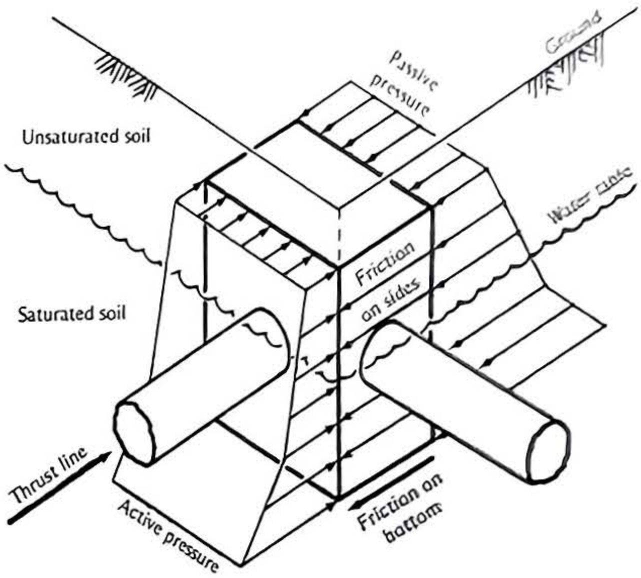
Example of a case where the water table is *at* the top of the block.

```
HIGH= 20.000
WIDE= 15.000
DEEP= 10.000
EI= 25.000
WTBL= 5.000
d.SAT= 130.000
d.USAT= 100.000
FR,DRY= 0.300
FR,WET= 0.200
∡= 35.000

FRICTION
      SIDES=90,038. LB
     BOTTOM=52,560. LB
PASSIVE
PRESSURE
          1,489,093. LB
ACTIVE
PRESSURE
           -282,805. LB
TOTAL
          1,348,885. LB
```

Example Calculation

ANCHOR BLOCK DESIGN (LINES BURIED IN COHESIONLESS SOILS)

Considerations:
- Thrust force
- Block dimensions
- Water table, if any
- Earth pressure at rest
- Passive earth pressure
- Active earth pressure
- Friction force acting on bottom face
- Friction force acting on sides



Earth pressure at rest:

$$Po = [\gamma_1 H_1 + (\gamma_2 - \gamma w)H_2](1 - \sin \phi) + \gamma w H_2$$

Passive earth pressure:

$$Pp = [\gamma_1 H_1 + (\gamma_2 - \gamma w)H_2]\tan^2\left(45 + \frac{\phi}{2}\right) + \gamma w H_2$$

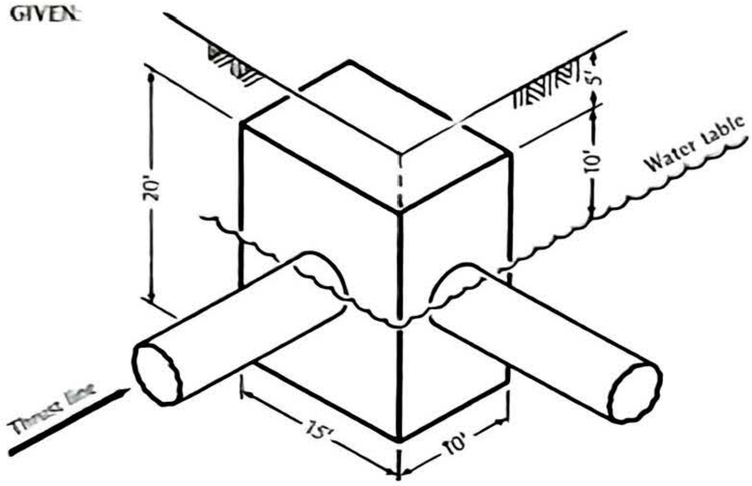
Active Earth Pressure

$$Pa = [\gamma_1 H_1 + (\gamma_2 - \gamma w)H_2]\tan^2\left(45 - \frac{\phi}{2}\right) + \gamma w H_2$$

Definitions:
γ_1 = Unsaturated soil density
γ_2 = Saturated soil density
Z = Depth of point where pressure is wanted
Zw = Depth of water table
γw = Density of water
ϕ = Angle of internal friction
H_1 = Depth of unsaturated soil
H_2 = Depth of saturated soil = $(Z - Zw)$

Sample Problem:
Design a Thrust Block That Will Restrain a Force of 1,500,000 lbs.

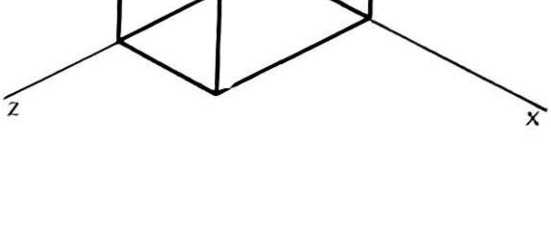
GIVEN:



γ_1 = (Unsaturated weight of soil) = 100 lb/ft^3
γ_2 = (Saturated weight of soil) = 130 lb/ft^3
ϕ = (Angle of internal friction) = 35° (sand)
μ_1 = (Friction coefficient of Unsaturated soil) = 0.3
μ_2 = (Friction coefficient of saturated soil) = 0.2

Solution:

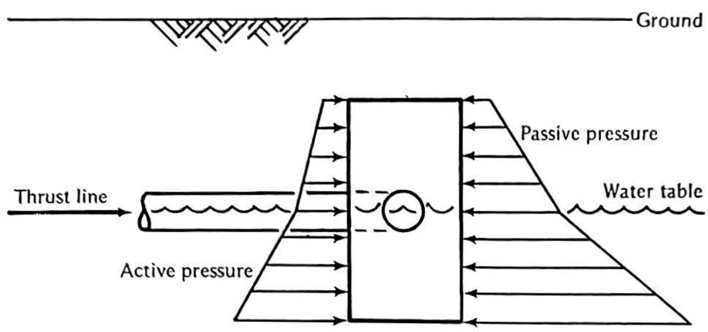
Assume the dimensions of the sides of the block and solve for the total restraining force. If the restraining force is greater than the applied thrust, then the block is overdesigned and could be sized down. If, on the other hand, the restraining force is less than the thrust applied, then increase one dimension of the block until the two forces are more or less equal.



Note that if the size of the block is insufficient to restrain the thrust, it is more advantageous to increase the size of the block in the Z-direction, unless the Y-dimension is increased while the top of the block remains at the same underground elevation.

For the sample problem, let us assume that for the block, Y = 20′, X = 10′, and Z = 15′.

Now, looking at the X-Y plane the pressure distribution diagram would be as follows:



The passive, active, the rest pressures must be found at the top and bottom of the block and at the water table level.

Pressure at Rest (Pr):

(Bottom) $Pr = [\gamma_1 H_1 + (\gamma_2 - \gamma w)H_2(1 - \sin \phi) + \gamma w H_2)$
$= [100(15) + (130 - 62.4)\ 10\ (1 - \sin 35°)] + 62.4\ (10)$
$= \underline{1551.90}\ \text{lb/ft}^2$

Note that H_2 becomes zero at and above the water table:

(Water Table) $Pr = [\gamma_1 H_1](1 - \sin \phi)$
$= [100(15)](1 - \sin 35)$
$= \underline{639.64}\ \text{lb/ft}^2$

(Top) $Pr = (100\ (5))\ (1 - \sin 35)$
$= \underline{213.21}\ \text{lb/ft}^2$

Similarly for passive pressure (Pp):

(Bottom) $Pp = \underline{8{,}653.81}\ \text{lb/ft}^2$

(Water Table) $Pp = \underline{5{,}535.26}\ \text{lb/ft}^2$

(Top) $Pp = \underline{1{,}845.09}\ \text{lb/ft}^2$

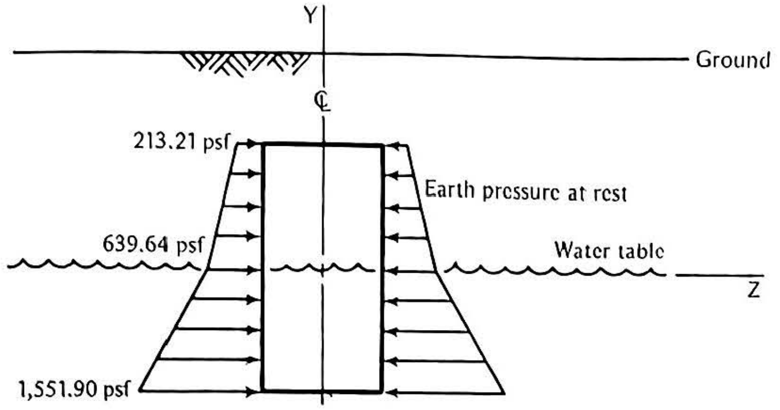
Active earth pressure (Pa):

(Bottom) $Pa = \underline{1{,}213.67}\ \text{lb/ft}^2$

(Water Table) $Pa = \underline{406.49}\ \text{lb/ft}^2$

(Top) $Pa = \underline{135.50}\ \text{lb/ft}^2$

Now calculate resisting friction force on the sides.



PRESSURE DISTRIBUTION DIAGRAM

The areas under the triangles will provide the resulting force per linear foot acting on the sides.

$$\text{Area above water table} = \frac{(639.64 - 213.21)\ 10}{2} + 213.21(10).$$
$$= 4{,}264.25 \text{ lb/ft}$$

Multiplying this times the block dimension parallel to the thrust or the X-dimension, we obtain the total force acting on one side *above* the water table:

FR (force due to earth pressure at rest) = 4,264.25(10) = 42,642.50 lbs
Ff (friction force) = 0.3 (42,642.5) = 12,792.75 lbs
Ff (two sides) = 12,792.75(2) = <u>25,585.50</u> lbs

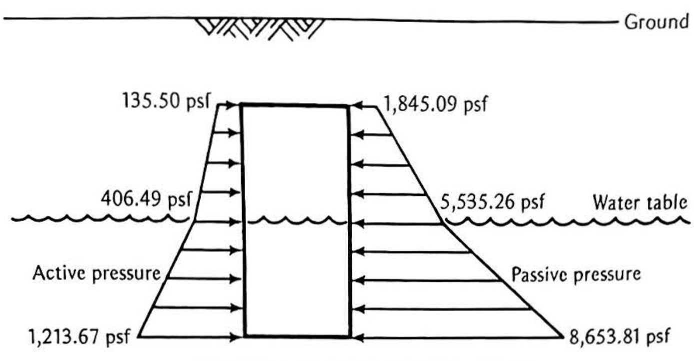
Similarly for the component below the water table:

$$\text{Area} = \frac{(1{,}551.90 - 639.64)10}{2} + 639.64(10)$$
$$= 10{,}957.70 \text{ lb/ft}$$

Again, total force acting on one side *below* the water table:

Fr = 10,957.70(10) = 109,577 lbs
Ff = 0.2 (109,577) = 21,915.4 lbs
Ff (two sides) = 21,915.4(2) = <u>43,830.80</u> lbs

Following a similar procedure, the active and passive components of the resisting force are found.



PRESSURE DISTRIBUTION DIAGRAM

Active pressure:

$$\begin{aligned}
\text{Area} &= \frac{(1{,}213.67 - 406.49)10}{2} + 406.49(10) \\
&\quad + \frac{(406.49 - 135.5)10}{2} \\
&\quad + 135.5(10) \\
&= 10{,}810.75 \text{ lb/ft} \\
\text{FA} &= 10{,}810.75(15) = \underline{162{,}161.25} \text{ lbs}
\end{aligned}$$

Passive pressure:

$$\begin{aligned}
\text{Area} &= \frac{(8{,}653.81 - 5{,}535.26)10}{2} + 5{,}535.26(10) \\
&\quad + \frac{(5{,}535.26 - 1{,}845.09)10}{2} \\
&\quad + 1{,}845.09(10) \\
&= 107{,}847.10 \text{ lb/ft} \\
\text{FP} &= 107{,}847.10(15) = \underline{1{,}617{,}706.5} \text{ lbs}
\end{aligned}$$

Finally, we must account for the friction force acting on the bottom face of the block.

Concrete = 150 lb/ft^3
Volume of block = $10 \times 20 \times 15 = 3{,}000$ ft^3

Total weight of concrete = 150(3,000) = 450,000 lbs.

To this we must subtract the displaced weight of water to account for the buoyancy effect on the portion of the block below the water table.

w = 62.4 lb/ft^3
Volume under saturated soil = $10 \times 10 \times 15 =$ 1,500 ft^3
Weight of water displaced = 62.4(1,500) = 93,600 lbs
Total weight = 450,000 − 93,600 = 356,400 lbs
FF = 356,400(0.2) = $\underline{71{,}280}$ lbs

Note that the friction force on the top face is ignored. Total resisting force:

$$\begin{aligned}
\text{FTOT} &= (\text{FF S}) + (\text{FP}) - (\text{FA}) + (\text{FF B}) \\
&= (25{,}586 + 43{,}831) + (1{,}617{,}707) - (162{,}161) \\
&\quad + (71{,}280) \\
&= \underline{1{,}596{,}243} \text{ lbs}
\end{aligned}$$

Total Force = 1,596,243 > 1,500,000 = Thrust
∴Thrust block is adequate

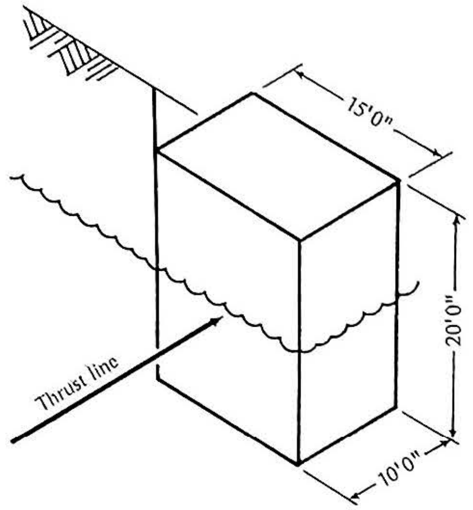
Note that the passive force is the highest component of the total resisting force.

Sample Problem

Program: HP-41CV-13 Title Buried Concrete Thrust Block Sizing

Sample Problem (Sketch if Desired)

HIGH = 20 ft
WIDE = 15 ft
DEEP = 10 ft
EI = 25 ft underground
WTBL = 15 ft underground
d.SAT = 130 lbs/ft^3
d.USAT = 100 lb/ft^3
FR, DRY = 0.3
FR, WET = 0.2
∡ = 35°



Input	Function	Display	Comments
	E	HIGH=	Initializes program. Prompts user for HIGH.
20	R/S	WIDE=	Stores HIGH in R01. Prompts for WIDE.
15	R/S	DEEP=	Stores WIDE in R02. Prompts for DEEP.
10	R/S	EI=	Stores DEEP in R03. Prompts for EI.
25	R/S	WTBL=	Stores EI in R04. Prompts for WTBL.
15	R/S	d.SAT=	Stores WTBL in R05. Prompts for d.SAT.
130	R/S	d.USAT=	Stores d.SAT in R06. Prompts for d.USAT.
100	R/S	FR,DRY=	Stores d.USAT in R07. Prompts for FR,DRY.
.3	R/S	FR,WET=	Stores FR,DRY in R08. Prompts for FR,WET.
.2	R/S	∡=	Stores FR,WET in R09. Prompts for ∡.
35	R/S	(Printed output)	Stores ∡ in R10.
		FRICTION SIDES= 69,416 LB BOTTOM= 71,280 LB	First the program determines whether the block is in *or* on the water table. If it is, then Flag 1 is set. H_1 is calculated and stored in R14. H_2 and H_0 are calculated and stored in R15 and R13, respectively. Next the soil coefficients Ko, Ka, and Kp are calculated and stored in R16, R17, and R18, respectively.
		PASSIVE PRESSURE 1,617,706 LB	
		ACTIVE PRESSURE -162,160 LB	
		TOTAL 1,596,242 LB	

Input	Function	Display	Comments
			A single subroutine is used to calculate the various earth pressures on the block. The pressures are calculated in the following order: Earth pressure at rest on the sides of the block, active earth pressure on the front face of the block, and passive earth pressure on the back face of the block. In each case, the force of the soil is calculated in lbs/ft of wall at three points: at the top of the block, at the water table, and at the bottom of the block. If the water table is at or below the bottom of the block, the force at the bottom is the same. From these three forces, the trapezoidal force distributions are calculated. When multiplied by the length of the block (WIDE or DEEP) the total force on the block is found. For soil pressure on the side of the block, the appropriate soil friction factors are used above and below the water table to get the friction on the sides. Finally, the program calculates the weight of the block, subtracts the buoyancy of the displaced water, and multiplies the final weight of the block by the appropriate friction factor. The results are printed and the program resets for another run.

Coding Form

Program Number HP-41CV-13 Title Buried Concrete Thrust Block Sizing

Step/Line Key Entry	Key Code	Comments
01♦LBL "TB"		Initialize program. Load alpha labels set pointer.
02 CF 01		
03 CLA		
04 "HIGH"		
05 ASTO 01		
06 "WIDE"		
07 ASTO 02		
08 "DEEP"		
09 ASTO 03		
10 "EI"		
11 ASTO 04		
12 "WTBL"		
13 ASTO 05		
14 "d.SAT"		
15 ASTO 06		
16 "d.USAT"		
17 ASTO 07		
18 "FR,DRY"		
19 ASTO 08		
20 "FR,WET"		
21 ASTO 09		
22 "∠"		
23 ASTO 10		
24 CLA		
25 1.01		
26 STO 00		
27 FIX 3		
28♦LBL "AA"		Input routine. Uses R00 as a pointer and counter.
29 CLA		
30 SF 12		
31 ARCL IND 00		
32 "⊢="		
33 PROMPT		Prompts for input and prints data.
34 STO IND 00		
35 ACA		
36 CF 12		
37 ACX		
38 PRBUF		
39 ISG 00		
40 GTO "AA"		
41 ADV		Determines location of the water table. If the block does *not* intrude into the water table, Flag 1 is set.
42 RCL 04		
43 RCL 05		
44 -		
45 X>0?		
46 GTO 10		
47 X=0?		
48 GTO 10		
49 CLX		

Step/Line Key Entry	Key Code	Comments
50 SF 01		
51♦LBL 10		H_1 is calculated and stored in R14. H_2 is stored in R15.
52 STO 15		
53 CHS		
54 RCL 04		
55 +		
56 STO 14		
57 RCL 01		H_o is stored in R13.
58 RCL 15		
59 -		
60 STO 13		
61 1		K_o is calculated and stored in R16.
62 RCL 10		
63 SIN		
64 -		
65 STO 16		
66 45		Ka is calculated and stored in R17.
67 RCL 10		
68 2		
69 /		
70 -		
71 TAN		
72 X↑2		
73 STO 17		
74 45		Kp is calculated and stored in R18.
75 RCL 10		
76 2		
77 /		
78 +		
79 TAN		
80 X↑2		
81 STO 18		
82 16		Calculate earth pressure at rest.
83 STO 00		
84 XEQ A		
85 RCL 22		The force of the earth on the sides of the block is calculated. If Flag 1 is set, the pressure of the water is *not* included. The friction force from the earth on the sides of the block is stored in R25.
86 RCL 03		
87 *		
88 RCL 09		
89 *		
90 RCL 23		
91 RCL 03		
92 *		
93 RCL 08		
94 *		
95 FS? 01		
96 GTO B		
97 +		
98♦LBL B		

Step/Line Key Entry	Key Code	Comments
99 2		
100 *		
101 STO 25		
102 1		Calculate active earth pressure.
103 ST+ 00		
104 XEQ A		
105 RCL 22		The force of the active earth pressure on the front of the block is calculated. If Flag 1 is set, the pressure of the water is *not* included. Fa is stored in R26.
106 RCL 02		
107 *		
108 RCL 23		
109 RCL 02		
110 *		
111 FS? 01		
112 GTO C		
113 +		
114♦LBL C		
115 STO 26		
116 1		Calculate passive earth pressure.
117 ST+ 00		
118 XEQ A		
119 RCL 22		The force of the passive earth pressure on the rear of the block is calculated and stored in R27. If Flag 1 is set, the pressure of the water is *not* included.
120 RCL 02		
121 *		
122 RCL 23		
123 RCL 02		
124 *		
125 FS? 01		
126 GTO D		
127 +		
128♦LBL D		
129 STO 27		
130 RCL 01		Weight of the concrete block is stored in R28.
131 RCL 02		
132 RCL 03		
133 *		
134 *		
135 150		
136 *		
137 STO 28		
138 RCL 15		The buoyancy of the displaced water is subtracted from the block weight.
139 RCL 02		
140 *		
141 RCL 03		
142 *		
143 62.4		
144 *		
145 ST- 28		
146 FS? 01		The correct friction factor is
147 GTO 20		

Step/Line	Key Entry	Key Code	Comments
148	RCL 09		chosen for the friction on the bottom of the block. If Flag 1 is set, the wet friction factor is used.
149	GTO 30		
150	♦LBL 20		
151	RCL 08		
152	♦LBL 30		
153	ST* 28		
154	"FRICTION"		The results are printed.
155	SF 12		
156	PRA		
157	CF 12		
158	CLA		
159	"SIDES="		
160	FIX 0		
161	ARCL 25		
162	"⊢ LB"		
163	ACA		
164	ADV		
165	"BOTTOM="		
166	ARCL 28		
167	"⊢ LB"		
168	ACA		
169	ADV		
170	SF 12		
171	"PASSIVE "		
172	PRA		
173	CLA		
174	"PRESSURE"		
175	PRA		
176	CLA		
177	CF 12		
178	ARCL 27		
179	"⊢ LB"		
180	ACA		
181	ADV		
182	SF 12		
183	"ACTIVE"		
184	PRA		
185	CLA		
186	"PRESSURE"		
187	PRA		
188	CLA		
189	CF 12		
190	"-"		
191	ARCL 26		
192	"⊢ LB"		
193	ACA		
194	ADV		
195	RCL 25		
196	RCL 26		

Step/Line	Key Entry	Key Code	Comments
197	-		The total resisting force of the block is the sum of all forces: active, passive and friction.
198	RCL 27		
199	+		
200	RCL 28		
201	+		
202	"TOTAL"		
203	SF 12		
204	PRA		
205	CLA		
206	CF 12		
207	ARCL X		
208	"⊢ LB"		
209	ACA		
210	ADV		
211	ADV		
212	ADV		
213	GTO "TB"		
214	♦LBL A		This subroutine calculates the earth pressures at the top and bottom of the block and at the water table. If the block does *not* intrude into the water table, this first section is skipped. Force at the bottom is stored in R19.
215	FS? 01		
216	GTO 25		
217	RCL 07		
218	RCL 14		
219	*		
220	RCL 06		
221	62.4		
222	-		
223	RCL 15		
224	*		
225	+		
226	RCL IND 00		
227	*		
228	62.4		
229	RCL 15		
230	*		
231	+		
232	STO 19		
233	♦LBL 25		Force at the water table is calculated and stored in R20.
234	RCL 14		
235	RCL 07		
236	*		
237	RCL IND 00		
238	*		
239	STO 20		
240	RCL 04		Force at the top of the block is calculated and stored in R21.
241	RCL 01		
242	-		
243	RCL 07		
244	*		
245	RCL IND 00		

Step/Line	Key Entry	Key Code	Comments
246	*		
247	STO 21		
248	FS? 01		The #/ft of wall is calculated below the water table and stored in R22. If Flag 1 is set, this section is skipped.
249	GTO 35		
250	RCL 19		
251	RCL 20		
252	-		
253	2		
254	/		
255	RCL 20		
256	+		
257	RCL 15		
258	*		
259	STO 22		
260	♦LBL 35		The #/ft of wall is calculated above the water table and stored in R23.
261	RCL 20		
262	RCL 21		
263	-		
264	2		
265	/		
266	RCL 21		
267	+		
268	RCL 13		
269	*		
270	STO 23		
271	RTN		
272	.END.		

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